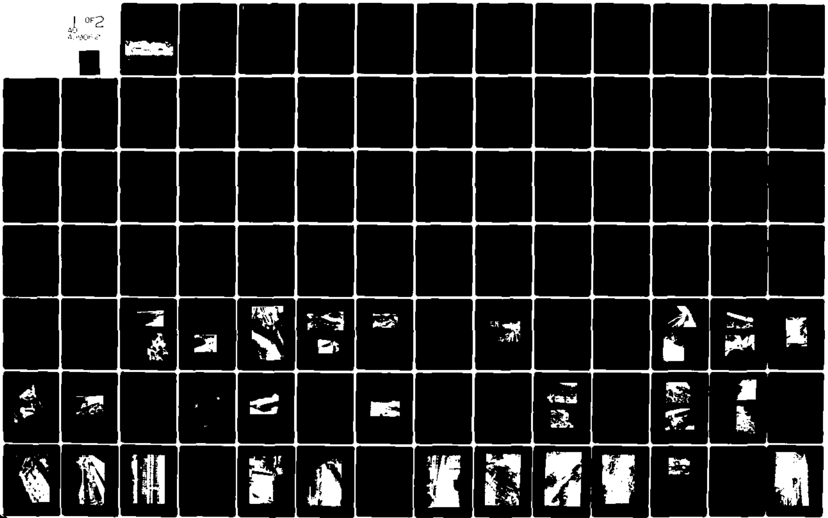
AD-A090 821 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
UTILIZATION OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICAT--ETC(U)
JUL 80 M P KEOWN, E A DARDEAU
UNCLASSIFIED WES/TR/HL-80-12 NL

1 OF 2
AD
A090821



LEVEL II (15)

TECHNICAL REPORT HL-80-12

UTILIZATION OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICATIONS

AD A090821

by

Malcolm P. Keown, Elba A. Dardeau, Jr.

Hydraulics Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

July 1980

Final Report

Approved For Public Release; Distribution Unlimited

DDC FILE

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Work Unit 3, Authorized by Section 32,
Water Resources Development Act, 1974

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: Technical Report HL-80-12	2. GOVT ACCESSION NO.: AD-A090 824
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): UTILIZATION OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICATIONS,	5. TYPE OF REPORT & PERIOD COVERED: Final report. Feb 73 - Feb 80
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Malcolm R. Keown, Elba A. Dardeau, Jr	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U. S. Army Engineer Waterways Experiment Station, Hydraulics Laboratory, P. O. Box 631, Vicksburg, Miss. 39180	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Work Unit 3, Section 32 Program
11. CONTROLLING OFFICE NAME AND ADDRESS: Office, Chief of Engineers, U. S. Army, Washington, D. C. 20314	12. REPORT DATE: July 1980
	13. NUMBER OF PAGES: 118
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): WES/TR/HL-80-12	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bank protection
Filter fabrics
Stream erosion

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A survey of literature, CE field offices, and filter fabric manufacturers was made to obtain published and unpublished information and case histories on the use of filter fabric as a component of streambank protection works. Properly selected and placed filter fabric may be considered as a substitute for part or all of a granular filter under revetment for situations where granular filter bedding materials are not readily available or cost-effective. Other

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411

20. ABSTRACT (Continued).

possible uses also are described. Available information on the currently specified methods of placing filter fabric is provided and cautions concerning its use are emphasized. Filter fabrics should not be used in lieu of granular filters on soils having more than 85 percent of material by weight passing the No. 200 sieve or in high energy environments. A glossary of basic terminology and a bibliography of relevant literature are included.

PREFACE

The study reported herein was performed from February 1978 through February 1979 by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Chief of Engineers, U. S. Army, under Work Unit 3, "Hydraulic Research on the Effectiveness of Bank Protection Methods," authorized by Section 32 of the Water Resources Development Act of 1974, Public Law 93-251. Section 32 may be cited as the "Streambank Erosion Control Evaluation and Demonstration Act of 1974."

This study was a multilaboratory effort planned by Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch, under the general supervision of Messrs. J. L. Grace, Chief of the Structures Division, H. B. Simmons, Chief of the Hydraulics Laboratory, and E. B. Pickett, WES Program Manager for the Section 32 Program. Also participating in this study were Messrs. M. P. Keown, E. A. Dardeau, Jr., and Dr. J. R. Rogers, of the Environmental Assessment Group (EAG) under direct supervision of Mr. J. K. Stoll, Chief of EAG, and under the general supervision of Dr. C. J. Kirby, Chief of the Environmental Resources Division, and Dr. J. Harrison, Chief of the Environmental Laboratory (EL). Invaluable guidance and background material were provided by Dr. E. B. Perry and Mr. S. P. Miller of the Soil Mechanics Division under the direct supervision of Mr. C. L. McAnear, Acting Chief of the Geotechnical Laboratory. Messrs. Keown and Dardeau prepared this report. Mr. R. M. Russell, Jr. (EL), prepared the figures.

Special acknowledgment is due the following without whose assistance the project objectives could not have been successfully met:

a. U. S. Army Corps of Engineers

   (1) Lower Mississippi Valley Division: Memphis, New Orleans, St. Louis, and Vicksburg Districts

   (2) Missouri River Division: Kansas City District

   (3) North Atlantic Division: New York and Norfolk Districts

   (4) North Central Division: Chicago and St. Paul Districts

   (5) Ohio River Division: Huntington, Louisville, Nashville, and Pittsburgh Districts

(6) South Atlantic Division: Charleston, Jacksonville, Savannah, and Wilmington Districts

(7) South Pacific Division: Sacramento and San Francisco Districts

(8) Southwestern Division: Albuquerque, Galveston, and Tulsa Districts.

b. U. S. Department of Transportation, Federal Highway Administration

(1) Washington, D. C.

(2) Sevierville, Tenn.

c. Private Concerns

(1) Advance Construction Specialties Co.

(2) American Enka Co.

(3) AMOCO Fabrics Co.

(4) Bay Mills Midland Limited

(5) Bradley Materials

(6) Carthage Mills

(7) Celanese Fibers Marketing Co.

(8) Crown Zellerbach Corp.

(9) E. I. DuPont de Nemours and Co.

(10) ERCO Systems, Inc.

(11) Erosion Control Systems, Inc.

(12) Kenross-Naue, Inc.

(13) Koch Brothers, Inc.

(14) Monsanto Textiles, Co.

(15) Nicolon Corp.

(16) Phillips Fibers Corp.

(17) Southern Natural Gas Co.

(18) Staff Industries, Inc.

(19) J. P. Stevens and Co., Inc.

(20) Tex-el, Inc.

Commanders and Directors of WES during this study and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acre-feet	1233.482	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609	kilometres
mils	0.0254	millimetres
pounds (force) per inch	175.1268	newtons per metre
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres
square yards	0.8361274	square metres
tons (2,000 lb, mass)	907.1847	kilograms
yards	0.9144	metres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

UTILIZATION OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICATIONS

PART I: INTRODUCTION

Objective

1. The objective of this report is to describe applications of and experiences with filter fabrics as a component of protection against streambank failures. Available information on the currently specified methods of installing filter fabric and cautions concerning its use for this purpose are also provided.

Streambank Failure

2. Streambank failures may be caused by the removal and transport of soil particles away from the channel sides and/or bottom by the bank and subsurface drainage, rapid drawdown of the stream water level, wave action, streamflow, or precipitation falling on the banks. Other contributing factors may include channel realignment (horizontal or vertical), placement of structures in the channel, changes in land use along the stream, groundwater seepage from the banks, liquefaction of the bank material, impact and scour by debris or ice, or effects from navigation in the channel. The implementation of effective streambank protection techniques is often required through reaches where active bank erosion is occurring in order to avoid significant losses of property, degradation of water quality, or loss of navigation channels.

Background

3. During early efforts to stabilize streambanks with a layer of heavy stones or broken rocks (riprap), the Corps of Engineers (CE) found that placement of a granular filter (crushed rock, gravel, sand) between a riprap blanket and prepared bank surface resulted in a considerable

improvement of revetment stability. Properly designed granular filters effectively prevented soil from being piped through the blanket, restrained the blanket from sinking into the soil, and permitted natural seepage from the streambank, thus avoiding a potential buildup of excessive hydrostatic pressure.

4. In 1956, as the result of severe North Sea storm and tidal damages, the Dutch Government initiated an extensive construction program to minimize the future deterioration of stream and coastal protection works. This program required the placement of large numbers of sandbags. Newly available experimental woven synthetic filter fabrics* were used to form the sandbags. This activity was the first known application of filter fabric material as a component of a major hydraulic structure (Figures 1 and 2).

5. The use of petrochemical-based synthetic materials did not find immediate acceptance in the American engineering community. As late as 1967, there were only two domestic sources of filter fabric,** although the use of fabric as a filter under interlocking block revetment had been reported as early as 1958 in Florida. A brief chronology of early uses of filter fabric for coastal and streambank applications is given in Table 1. The recent enactment of Federal and State legislation (1970) has made the purchase of American-made filter fabric more economically advantageous than that of comparable European material.

6. Prior to 1970, no site-specific cost comparisons for using filter fabric as a substitute for granular filters were readily available. The initial economic case study of record was conducted by the U. S. Army Engineer District, Memphis (LMM), in 1966. Results of this study indicated that filter fabric could be put in place under articulated concrete mattresses (ACM) for $9.71/square (100 ft^2) as opposed to $8.03/square for a 4-in.-thick granular filter (Fairley et al. 1970). However, a factor not considered in this comparison was the repair cost

---

* More recently also called geotextiles.

** A current list of commercial concerns that market filter fabric products is provided in Appendix A.

of undermined ACM, which comprises a large percentage of upper bank repairs along the Lower Mississippi River. A study of repairs made through this reach was conducted to determine what cost reductions could be realized by the use of adequate filter material. Even though it was not possible to accurately isolate all repairs attributable to the loss of granular filter and subgrade material through the mattresses, costs compiled from many construction sites through fiscal years 1967, 1968, and 1969 indicated that the repair cost for undermined ACM was $1.73 per square. No repairs were needed where filter fabric had been placed under the mattresses. Thus, fabric was directly competitive with granular filters through this LMM reach on a short-term basis.

7. As the utility of filter fabric became apparent, the Office, Chief of Engineers (OCE), directed the U. S. Army Engineer Waterways Experiment Station (WES) to conduct a study to determine the extent and diversity of use of this material by the CE Divisions and Districts. The findings of this study (Calhoun 1969) indicated that although there was a wide and varied use of filter fabrics by the CE, a test program was needed to define the engineering properties of the fabrics when used for filter and drainage applications. Much of the reported fabric usage had been as a filter placed under riprap with lesser amounts being placed around pipes, well screens, and piezometer tips. In some Districts the fabric material was also used as a substitute for a granular layer in a multilayered filter, for surface erosion control, and for grout stops.

8. The study described in paragraph 7 became the first phase of a broader program conducted at WES (1967-1972). As part of this program, seven filter fabrics (six woven and one nonwoven) were evaluated by chemical, physical, and filtration testing. Additional work by LMM provided needed information on the large-scale field application of filter fabric. From the results of the WES program (Calhoun 1970 and 1972) and CE project experience, OCE guide specifications were developed for the field use of filter fabric (OCE 1973).

9. As nonwoven or random fiber fabrics became available, an additional examination of fabrics and methods of evaluating their engineering properties was considered necessary. Laboratory testing was

conducted at WES during 1974-1976 to refine existing test methods for woven fabric and to develop new methods for the evaluation of nonwoven fabrics. Results of this effort and further field experience provided the basis for new CE guidelines (OCE 1977) for the field use of woven and nonwoven filter fabrics. In addition to the WES work, laboratory testing of filter fabrics has been conducted by the Bundesanstalt für Wasserbau in Germany (List 1977) (350 fabrics) and Oklahoma State University (Haliburton et al. 1972) (28 fabrics).

Scope and Approach

10. This study was initiated by conducting a literature survey to determine what documentation was available relevant to the use of filter fabric for streambank protection applications.* After the survey was completed, each CE District was contacted to obtain information on unpublished or limited distribution documents pertinent to filter fabric utilization for streambank protection, and to acquire case histories related to the use of filter fabric as a component of streambank protection works. In addition, all filter fabric manufacturers known to the participants of this study were contacted to obtain recent documentation on fabric usage and to gather the cost information given in Tables 2 and 3 for currently available fabrics.** The resulting information collected from the above sources has been collated into the narrative documentation which is provided herein. A glossary containing the basic terminology related to the use of filter fabric for streambank protection applications (Appendix B), and a bibliography relevant to filter fabric technology and application as directly related to streambank protection (Appendix C) are included as part of this report.

---

* The foundation of this survey was based on previous work completed by WES under the Section 32 Program (Keown et al. 1977).

** A tabulation of 1978 material costs for selected commercially available woven and nonwoven fabrics is presented in Tables 2 and 3, respectively. In-place costs are difficult, if not impossible, to estimate on a generalized basis because of the many variables involved such as bank preparation, transportation, etc.

PART II: FUNCTIONAL USES OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICATIONS

11. The availability of filter fabric for a variety of engineering applications has fostered consideration and use of this material as a component of streambank protection works. Two applications currently employ filter fabric as: (a) a substitute for part or all of a granular filter; and (b) container material for sack revetment. A brief description of both applications is provided in this part; however, the application of filter fabric within the CE has generally been restricted to usage as a substitute for granular filters; thus, the remaining parts of this report are directed toward this application.

Substitute for Granular Filter

12. Granular filters are often placed beneath revetment to prevent piping of soil through the revetment, to prevent the revetment from sinking into the soil, and to permit natural seepage from the streambank and thus prevent the buildup of excessive hydrostatic pressure. Ideally, a filter bed of crushed rock, gravel, or sand is placed between the revetment and the prepared bank to provide a gradual reduction in particle size until the particles blend with the natural bank material. To prevent infiltration of the bank material being drained into the filter material, the following conditions should be met (see EM 1110-2-1913, 1978):

Stability

$$\frac{\text{15 percent size* of filter material}}{\text{85 percent size of material being drained}} \leq 5$$

and

$$\frac{\text{50 percent size of filter material}}{\text{50 percent size of material being drained}} \leq 25$$

* The "15 percent size" of the material (i.e. D_{15}) is that sieve size that will pass 15 percent by weight of the material.

To assure that the filter material is much more permeable than the material being drained, the following condition should be met:

Permeability

$$\frac{\text{15 percent size of filter material}}{\text{15 percent size of material being drained}} \geq 5$$

13. When the use of granular material has not been feasible, filter fabric has been substituted for one or more layers or has completely replaced the granular filter (Figure 3). By far, the most common use for filter fabric as a substitute for a granular filter has been placement beneath stone riprap (Figures 3 and 4); however, additional application has been realized by placing the fabric below articulated concrete mattresses (Figure 5), gabions (Figure 6), and precast cellular blocks (Figure 7). The fabric has also been used as a carrier for precast cellular blocks attached to the fabric with adhesive material (Figure 8) and as a foundation support for a dike or jetty (Figure 9).

14. The formation mechanism of a fabric-soil filtration system is not well understood for streambank protection applications where the revetment is placed directly on the fabric. A study conducted by Marks (1975) to evaluate the behavior of filter fabric for subdrainage use has been broadly extended toward understanding this mechanism; however, that study was limited to one fabric type subjected to constant-head, steady-state flow. According to Mark's study, the soil particles of the streambank would be generally well distributed immediately after placement of the filter fabric and revetment (Figure 10a). As filtration begins, the soils particles are reoriented. A "bridging network" begins to form, and some of the fine particles "pipe" through the fabric (Figure 10b). In the mature fabric-soil system the bridging network is completed (Figure 10c). A porous filter cake has formed, and the piping of fine particles through the fabric is virtually eliminated.

15. In accordance with specifications presented in paragraph 23 of this report, filter fabric should not be used in lieu of a granular filter on soils having more than 85 percent of material by weight passing the No. 200 sieve. Also, in the present absence of pertinent laboratory

data and field experience, caution is advised on the use of filter fabrics in lieu of graded granular filters beneath revetments subject to intensely turbulent flow. Additional revetment thickness may be required to keep the fabric in a low-turbulence environment free of adverse and fluctuating pressures.

Sack Revetment

16. Sacks made of burlap or paper and filled with soil, sand, soil-cement, or sand-cement mixtures have been used for erosion protection around hydraulic structures and for emergency work along levees and streambanks during floods (Figure 11). The bags eventually rot or become damaged by cattle traffic or vandals; therefore, only bags filled with soil-cement or sand-cement mixtures can maintain the longer-term benefits of the bags' concentrated mass.

17. Although soil-cement- and sand-cement-filled bags may be effective against stream attack, the revetment itself is often relatively impermeable. As a result, this type of revetment is subject to failure from back pressure when the bank is saturated or rapid drawdown occurs, if drainage relief is not provided. Bags made of long-life, nondeteriorating fabric and filled with uncemented sand can allow bank drainage through the sand and fabric material. Although such sack revetments using filter fabric material have not yet been placed on a widespread basis, limited reports indicate that this may be a succesful approach to the construction of sack revetment.

PART III: FILTER FABRIC DESIGN CONSIDERATIONS

18. Three factors must be carefully weighed during the selection and placement of a specific filter fabric for a given project application. These factors are:

- a. Filtration. The fabric must act as a filter, i.e. the flow path through the fabric mesh must be fine enough to prevent continuous infiltration and passing of soil, yet large enough to allow water to pass freely.
- b. Chemical and physical properties. The fabric's chemical composition must be such that it will resist deterioration from climatic conditions and from chemicals found in the soil and water, and must possess sufficient strength so that it will not be torn, punctured, or otherwise damaged during placement and through continued use.
- c. Acceptance of mill certificates and compliance testing. The fabric must meet Government standards for acceptance of mill certificates and compliance testing.

These topics are further developed below to guide the designer in selecting a filter fabric that will perform satisfactorily under given conditions; placement of the fabric is treated in Part IV.

19. The only CE guidelines (OCE 1977) relative to the use of filter fabric as a component of a streambank works are directed toward the placement of riprap on the fabric; however, the specifications provided in these guidelines can be generally extended to the placement or support of other revetment materials on the fabric, i.e., articulated concrete mattresses, gabions, precast cellular blocks, carrier fabrics, and dike foundation supports (Figures 5-9). Thus, because the information in this report is based largely on the current CE guidelines, the concepts developed in this part and the following parts should be generally applicable to various other applications as noted above.

Filtration

20. The Equivalent Opening Size (EOS) of a fabric and the Gradient Ratio (GR) of the fabric-soil filtration system determine the filtration

characteristics of a given fabric. These two parameters are discussed below.

Equivalent opening size

21. The EOS of a filter fabric is defined as the number of the U. S. Standard Sieve having openings closest in size to the fabric openings. A procedure to determine the EOS is thus a test that provides the designer with information needed to select a filter fabric which will minimize the passage of soil particles based on the grain-size distribution of the bank material. The EOS for a specific fabric is determined by testing five unaged fabric samples. Prior to testing, 50 gm of each of the following six fractions of standard glass beads must be obtained:*

Fraction	Sieve Size Range*		Corresponding EOS*
	Passing	Retained On	
1	No. 18	No. 20	No. 20
2	25	30	30
3	35	40	40
4	45	50	50
5	60	70	70
6	80	100	100

* All entries in tabulation are U. S. Standard Sieve numbers. (See Figure 12 for equivalent grain size.)

Within each of the six fractions, 95 percent of the beads should be within the specified size range. The fabric to be tested is then affixed to a standard 8-in.-diam sieve having openings larger than the largest beads to be used in the test. The fabric is attached to the sieve in such a manner that no beads can pass between the fabric and the sieve wall. Each successively coarser fraction is then dry-sieved for 20 min with an automatic shaker to determine that fraction of which

* Suitable glass beads can be obtained from:
Cataphone Division
Ferro Corporation
P. O. Box 2369
Jackson, Mississippi 39205
Telephone: (601) 939-4631

5 percent or less by weight of the standard beads will pass the test fabric. Shaking shall be accomplished as described in paragraph 2d(1)(g), Appendix V, EM 1110-2-1906, except the time for shaking is 20 min. Once the correct fraction is known, the corresponding EOS for the test fabric can be determined (last column of tabulation).

22. The 1977 specifications for filter fabric usage (OCE 1977) are interpreted as applying to any fabric type, i.e. woven or nonwoven. The nonwoven fabrics with random fiber mats do not have well-defined openings for the application of an EOS test. A Forest Service report (Steward et al. 1977) on fabric use states:

> "The EOS test, developed for designing and specifying woven fabric filter systems, does not appear to be appropriate for a nonwoven filter system... . Nonwoven fabrics are manufactured by extrusion and random orientation of fibers in the fabric. The resulting EOS of the nonwoven fabrics is variable and built into the fabric to varying degrees, depending on the fabric weight and the process used to bond the fibers together."

Nonwoven fabric manufactuers have been quick to point out that the yarn and weaving processes used for woven fabric production are often somewhat nonuniform and thus the finished woven fabric may reflect some EOS variations. Results from EOS testing indicate that the glass beads will travel to the slightest opening larger than what is designed into the woven fabric, thus causing the sample to be misclassified; in almost every square yard of woven fabric, there are openings which could cause an incorrect classification.

23. For a given field application, the EOS must be known for the various fabrics available for placement at the construction site. The correct fabric can then be selected to ensure that the fabric and bank soil are properly matched to provide an effective filtration system. The following criteria (OCE 1977) should be used to select the correct filter fabric:

a. For fabric to be placed adjacent to granular materials

containing 50 percent or less fines* by weight, the following ratio must be satisfied:

$$\frac{\text{85 percent passing size of soil (mm)}}{\text{EOS of filter fabric No. (mm)}} \geq 1$$

b. For fabric to be placed adjacent to all other type soils: EOS no larger than the openings in the U. S. Standard Sieve No. 70 (0.211 mm). Filter fabric should not be placed on soils where 85 percent or more of the soil materials are fines (No. 200 sieve).

To reduce the chance of clogging, no fabric should be specified with an EOS smaller than the openings of the No. 100 sieve (0.149 mm). When possible, it is preferable to specify a fabric with openings as large as allowed by the criteria. Thus, the EOS selected for a fabric to be used with soils falling into criterion a. must be no smaller than No. 100 (0.149 mm) and must be equal to or less than the 85 percent passing size of the soil. The EOS specified for a fabric to be used with soils falling into criterion b. must be no smaller than No. 100 (0.149 mm) and no larger than No. 70 (0.211 mm); note that soils under criterion b. must have at least 50 percent but no more than 85 percent fines by weight.

24. To illustrate the use of the filter criteria, consider the two soil gradations shown in Figure 12. Soil No. 1 is a medium to fine sand containing about 9 percent silt, while soil No. 2 is a silt containing some medium to fine sand. The 85 percent passing size of both soils is 0.49 mm. Since soil No. 1 is a granular material containing less than 50 percent silt, the criterion applied is that the 85 percent passing size of the soil must be equal to or greater than the EOS of the fabric. Therefore, the fabric EOS should not exceed 0.49 mm (No. 40 sieve) but must be larger than 0.149 mm (No. 100 sieve). Ideally the larger EOS should be selected for placement if the fabric material is available. Soil No. 2 contains more than 50 percent silt,

* Fines are here defined as those soils that will pass a U. S. Standard Sieve No. 200 (0.074 mm).

thus the EOS can be no larger than 0.211 mm (No. 70 sieve) but must be larger than 0.149 mm (No. 100 sieve). Again, the larger EOS should be used if the fabric material is available.

Gradient ratio of fabric-
soil filtration system

25. The GR of a given fabric-soil filtration system is the ratio of the hydraulic gradient over the 1 in. of soil immediately next to the fabric (i_f), to the hydraulic gradient over the 2 in. of soil between 1 and 3 in. above the fabric (i_g).

$$GR = \frac{i_f}{i_g}$$

If the fine particles in the soil adjacent to the fabric become trapped in or on the fabric (clogging), the GR will increase. Likewise, if the fine soil particles move through the filter fabric (piping), the GR will decrease. CE guide specifications indicate that the GR should not exceed 3 (OCE 1977).

26. Determination of the GR is a flow performance test conducted in accordance with EM 1110-2-1906, Appendix VII, with the following modifications:

a. The soil specimen shall be 5 in. in diameter and 4 in. in height (Figure 13) and shall consist of the soil that is to be protected in the field by the fabric.

b. A piece of hardware cloth with 1/4-in. openings is placed beneath the filter fabric specimen to support it. The fabric and the hardware cloth should be clamped between flanges so that no soil or water can pass around the edges of the cloth.

c. Piezometer taps shall be placed 1 in. below the fabric, and 1, 2, and 3 in. above the fabric.

d. Tap water shall be permeated through the specimen at a constant head for a continuous period of 24 hr. The GR shall be determined from piezometer readings taken at the end of the 24-hr period.

27. Documentation reported in a Forest Service report (Steward et al. 1977) indicates that the GR test used by the CE appears to be applicable to both the selection of woven and nonwoven fabrics; in addition,

the tests for either type of fabric need to be continued until the GR becomes constant, typically 10 days but possibly as long as 3 to 4 weeks (Marks 1976). The GR test should be performed under intermittent flow conditions representative of fluctuations in the water table or seepage flow.

Chemical and Physical Properties

28. In addition to filtration properties, the designer must include chemical and physical (strength and slippage) properties in a project plan to assure the correct selection of a specific filter fabric. These considerations are developed below.

Chemical composition

29. Current CE construction specifications (OCE 1977) require that the plastic yarn used to manufacture filter fabric should consist of a long-chain synthetic polymer composed of at least 85 percent by weight of propylene, ethylene, ester, amide, or vinylidene-chloride, and shall contain stabilizers and/or inhibitors added to the base plastic (if necessary) to make the filaments resistant to deterioration due to ultraviolet and heat exposure. No CE guidelines are provided for non-plastic fabrics.

Strength characteristics

30. Plastic filter fabric used for CE projects must conform to the physical strength requirements provided in Table 4. In addition, the fabric should be fixed so that the yarn filaments will retain their relative position with respect to each other, and the edges of the fabric should be finished to prevent the outer yarn filament from pulling away from the fabric. No CE guidelines are provided for non-plastic fabrics.

31. One of the most thorough fabric strength testing studies was performed by Oklahoma State University for the U. S. Army Engineer District, Mobile (SAM) (Haliburton et al. 1978). The objective of the testing effort was to find a fabric capable of supporting a dredge-fill embankment in Mobile Harbor. Ten woven fabrics (including one fiberglass fabric) and eighteen nonwoven fabrics were tested in uniaxial

tension, in both the warp and fill directions (see Appendix C for definitions), using at least three samples (6 in. wide × 12 in. long) of each fabric. The purpose of this test was to determine the stress-strain characteristics of each fabric and to identify those fabrics which had the highest ultimate tensile strength and stress-strain modulus. A minimum strength criterion of 100 lb/in. in the warp direction at 10 percent strain was specified for any fabric that would possibly be used in the Mobile Harbor Project.

32. Only four woven plastic fabrics (Nicolon HD 10,000 Poly-Filter X, Advance Construction Specialties Laurel Erosion Control Cloth-I, and Nicolon MD 7,500) and the woven fiberglass fabric (Bay Mills 196-380-000) exceeded the criterion with the other 23 fabrics having a wide variation in uniaxial tension and stress-strain behavior (a complete listing of the test results is provided in Table 3.1 of Haliburton et al. 1978). The five stronger fabrics exceeding the strength criterion were subjected to additional testing for determination of soil-fabric slippage resistance (discussed in the next section), the effects of immersion and water absorption on developed tensile strength, and creep behavior. Creep is the tendency of a fabric to elongate with time under a continuously applied static load. The results were:

a. Both Nicolon materials were found to have minimal creep tendency and strength loss after soaking.

b. The Bay Mills fiberglass fabric had zero creep tendency but was not tested for soaking strength loss.

c. Poly-Filter X had moderate to high creep tendencies and the highest strength loss (32 percent) after soaking.

d. The Advance Type I fabric had high to extremely high creep tendencies and an 18 percent strength loss after soaking.

33. The collective conclusions derived from this study indicate:

a. In general, woven fabrics are considerably stronger in uniaxial tension than nonwoven fabrics, with the general ranking, in order of decreasing strength, being:

(1) Heavy to intermediate-weight woven fabrics.

(2) Intermediate to lightweight woven and heavy to intermediate-weight nonwoven fabrics.

(3) Lightweight nonwoven fabrics.

b. Woven fabrics generally fail from localized strand breaking in tension or diagonal tearing suggestive of shear failure. Nonwoven fabrics fail primarily from diagonal tearing, excessive elongation, or strength drop without outward signs of fabric rupture or tearing.

Slippage

34. No direct guidance has been provided relevant to slippage between the soil slope and fabric, or the fabric and revetment material; however, the current guide specifications (OCE 1977) do state that securing pins should be used to keep the fabric in place. The pin spacing specifications are 2 ft for slopes steeper than 1V on 3H, 3 ft for slopes of 1V on 3H to 1V on 4H, and 5 ft for slopes flatter than 1V on 4H (OCE 1977). Several U. S. Army Engineer Districts have reported (Calhoun 1970) some tearing of filter fabric at the seams and pins due to stone sliding down 1V-on-2H slopes (Figure 14). This problem has been minimized in the Divide Cut Section of the Tennessee-Tombigbee Waterway by loosely placing the fabric over the prepared bank, using only enough pins to hold the fabric in position prior to placement of the stone (Figure 15). After placement, the stone moves toward its permanent resting position; as this occurs the loosely placed fabric is allowed to move with the stone, thus avoiding the pin and seam tears which often occur on steep slopes where many pins are used.

35. The "effective" slippage resistance can be raised by adequate toe protection; a toe failure encourages the in-place stone to slide, thus leaving the bank unprotected except for the fabric and possibly resulting in torn fabric as the stone slides down the bank. The U. S. Army Engineer District, St. Paul, placed a fine sand bedding under rather than on top of filter fabric as part of a revetment construction project on the Vermillion River at Hastings, Minn. Later onsite inspections indicated that by placing the stone in direct contact with the fabric, depressions were made in the fabric at the stone-fabric contact points, thus apparently increasing the slippage resistance.

36. The Oklahoma State University/SAM study (Haliburton et al. 1978) showed that soil-fabric frictional properties can be evaluated

by a direct shear test (relative displacement of bank material against the fabric) under various values of applied normal loading. The direct shear test for the five acceptable fabrics (paragraph 32) against loosely compacted sand indicated that the fabric could be placed on a bank of 29 deg to 33 deg before slippage occurred; testing with the sand in a heavily compacted state yields higher angles, ranging from 37 deg for Advance Type I to 46 deg for Nicolon 66186.

Acceptance of Mill Certificates and Compliance Testing

37. The 1977 Civil Works Construction Guide Specification for Filter Fabric (OCE 1977) states that all brands of filter fabric and all seams to be used shall be accepted on the following basis:

> "The Contractor shall furnish the Contracting Office, in duplicate, a mill certificate or affidavit signed by a legally authorized official from the company manufacturing the fabric. The mill certificate or affidavit shall attest that the fabric meets the chemical, physical, and manufacturing requirements stated in this specification."

38. If the Contracting Officer wishes to test one or more filter fabric samples for compliance (which is highly recommended), the contractor is required to provide to the Government fabric samples for testing to determine compliance with any or all of the requirements in the project specifications. When samples are to be provided, they must be submitted for testing a minimum of 60 days prior to placement.

PART IV: PLACEMENT OF FILTER FABRIC

39. The proper placement of filter fabric requires that the bank first be cleared of vegetation, debris, etc. After the streambank has been sloped, graded, and compacted to meet project specifications, the fabric is removed from the protective covering used for shipment and spread on the prepared bank. The fabric edges are overlapped and joined after which the fabric is secured on the bank by pinning. The revetment materials are then placed on the fabric, completing the streambank protection works. These procedures are discussed below.

Shipment and Storage

40. Due to possible damage resulting from solar ultraviolet radiation or improper handling, the fabric should be wrapped in a heavy duty protective covering such as burlap during shipment and storage (Figure 16). In addition, the fabric must be protected from mud, dust, and debris and from temperatures in excess of 140°F. At the time of placement, the fabric should be rejected if it has rips, holes, flaws, or evidence of deterioration or damage incurred during manufacture, shipment, or storage.

Site Preparation

41. The streambank soil surface should be graded to a relatively smooth plane, free of obstructions, depressions, and soft pockets of material. Depressions or holes in the soil should be filled before the fabric is placed since the fabric could bridge such depressions and be torn when the revetment materials are installed. Rock, stones, and other debris should be removed prior to fabric placement to prevent the fabric from being damaged or pinched between these objects and the revetment material.

Seams

42. The 1977 Civil Works Specifications (OCE 1977) require that fabric seams must be sewn with thread meeting the chemical requirements

stated in paragraph 30 applicable to plastic yarn (Figures 17 and 18) or should be bonded by cementing or by heat. Seams should be tested in accordance with method ASTM-D-1683, using 1-in. square jaws and a 12-in. per minute constant rate of traverse. The strengths should not be less than 90 percent of the required tensile strength of the unaged fabric in any principal direction.

43. Most fabrics are manufactured in 6-ft widths. To reduce the number of overlaps, narrow sections can be assembled together by the manufacturer to produce wider sections. Preassembled sections of 36-ft widths or more are advantageous in order to reduce the number of overlaps that must be made at the construction site. Laps and seams alone often account for up to 25 percent of the total project cost when 6-ft widths are used. Some fabric companies market widths of up to 66 ft.

Securing Pins

44. The filter fabric should be secured to the streambank to prevent movement prior to placement of the revetment material (Figure 19). The revetment material will hold the fabric in place once the structure has been completed (unless the bank is very steep, see paragraph 45); thus, the devices used to secure the fabric do not need to be made of "permanent" or long-lasting materials. The securing pins should be inserted through both strips of overlapped fabric along a line through the midpoint of the overlap at intervals no greater than those specified in paragraph 45.

45. Securing pins are generally available from the filter fabric manufacturer or distributor. One particular type of pin that has performed well under most conditions is the 3/16-in.-diam, 18-in.-long steel pin, pointed at one end and fitted with a 1-1/2-in.-diam washer on the other; these pins can be used in rather firm soils such as dense silty material. Longer pins are advisable for use in loose materials such as sands. When pins are used, the following maximum spacings between pins are recommended:

Slope	Spacing, ft
Steeper than 1V on 3H	2
1V on 3H to 1V on 4H	3
Flatter than 1V on 4H	5

Several U. S. Army Engineer Districts have reported some tearing of filter fabric at the seams and pins due to stones sliding down 1V-on 2H-slopes; however, this problem does not normally occur where the slopes are 1V on 3H or flatter (paragraph 34).

46. Problems are often encountered in maintaining the placement position when fabrics are laid on loose sands on windy days. Such problems can usually be remedied by placing additional pins along the laps and within the fabric or by placing stones on the fabric. If windy conditions are expected, it is advisable to have additional pins at the construction site and comply with paragraph 50.

Placement of Fabric on Bank

47. The heavy duty protective covering can be taken off the fabric roll somewhat before the time of placement; however, the fabric should not be left exposed to ultraviolet deterioration for extended periods. After the protective covering is removed, the fabric should be laid flat (but not stretched) on the prepared bank with no folds in the material (Figure 20). During placement of the revetment, the fabric should be protected at all times from contamination by surface runoff. Any contaminated fabric should be removed and replaced with new fabric. A period of low streamflow should be selected to facilitate fabric installation, provided the period is compatible with the construction schedule.

48. To prevent soil leaching, the filter fabric strips should be properly joined together by seams (paragraphs 42 and 43) and/or overlaps. The strips should be placed with the longer dimension parallel to the current when used along streams where currents acting parallel to the bank are the principal means of attack (Figure 21a). The upper strip of fabric should overlap the lower strip (like roofing shingles are commonly placed) and the upstream strip should overlap the downstream strip. To

avoid having long sections of continuous overlap, the overlaps at the ends of the strips should be staggered at least 5 ft as shown in Figure 21a. The revetment and fabric should extend below mean low water to minimize erosion at the toe (Figure 22).

49. When the revetment materials and fabric are subject to wave attack, the customary construction practice is to place the fabric strips vertically down the slope of the bank (Figure 21b). The upper vertical strip should overlap the lower strip. The fabric usually needs to be keyed at the toe to prevent uplift or undermining (Figure 23). It is important that the key trench be below mean low water to prevent erosion of material adjacent to the trench and the subsequent loss of the trench. When it is not possible to maintain vertical trench walls, the fabric may have to be keyed as shown in Figure 24. Here the trench is excavated and the walls are allowed to assume a stable slope. The key at the top (shown in Figure 23) is usually not necessary unless wave action is expected to reach that elevation or if overbank drainage is anticipated. A key trench at top bank should also be used for streambank protection works subject to current attack where there is an overbank drainage problem.

Placement of Revetment on Fabric

50. If filter fabric is considered adequate for a selected project, the placement of revetment materials on filter fabric must be conducted in such a manner that the fabric is not torn or punctured. The most common material placed on fabric for streambank protection applications is stone riprap. Heavy and angular stone dropped from heights even less than 1 ft can damage the filter fabric. Displacement and settling of stone after placement could also result in ultimate failure. Various precautions have been taken in previous applications to prevent damage of the fabric, such as a cushioning layer of gravel, etc., between the filter fabric and the riprap (Figure 25). However, care should be taken to ensure that any cushioning layer does not form a low permeability layer between the stone and fabric (see paragraph 12 for desirable

gradation). Some problems related to the extra care required for revetment placement can be avoided by using a granular filter instead of filter fabric.

Measurement and Payment

51. Current CE guidelines (OCE 1977) specify that measurement for payment of filter fabric is made on an "in-place" basis. No allowance is made for fabric material in the laps and seams. Payment is therefore made at a contract unit price which includes furnishing all plant, labor, material, and equipment and performing all operations in connection with placing of the fabric. No count or payment is made for the securing pins, which are included in the contract unit price. No additional payment will be made for the material in and placement of a cushion layer used to permit increased stone drop height. All costs incidental to this phase of the construction effort must be included in the contract unit price.

PART V: CASE HISTORIES

52. Present CE guidelines (OCE 1977) and published literature deal principally with the placement of riprap on filter fabric. To demonstrate this use and other varied uses, the following case histories were prepared.

- a. Ohio River at Wheeling, W. Va. (riprap placed on filter fabric).
- b. Mississippi River at Island 40 near Memphis, Tenn. (articulated concrete mattress bonded to filter fabric).
- c. Little Rockfish Creek at Hope Mills, N. C. (gabions placed on filter fabric).
- d. Red River at Morameal Revetment near Shreveport, La. (precast cellular blocks placed on filter fabric).
- e. Tangipahoa River near Independence, La. (precast cellular blocks bonded to carrier fabric).

The location of each of the five sites is shown in Figure 26. A brief narrative consisting of known construction history, documented successes or failures of the revetment, and reasons for this performance is presented below for each site.

Ohio River at Wheeling, W. Va. (Riprap on Filter Fabric)*

53. In 1974 the U. S. Army Engineer District, Pittsburgh (ORP), completed construction of Hannibal Locks and Dam on the Ohio River at mile 126.4.** As a result of this action, the pool that includes the Wheeling, W. Va., reach was raised from an elevation of 617.8 ft† (elevation of the old Dam 13 pool) to its present normal pool elevation of 623 ft which extends upstream to Pike Island Locks and Dam (mile 84.2). The 623-ft elevation of the new Hannibal pool required raising the elevation

---

* Unpublished file information provided by the U. S. Army Engineer District, Pittsburgh, CE.

** Ohio River mileage begins with mile 0 at the confluence of the Allegheny and Monongahela Rivers. This system of mileage terminates at mile 981.5 at Cairo Point, Ill., the confluence of the Ohio and Mississippi Rivers (Pittsburgh District 1975).

† All elevations noted in this report are referenced to mean sea level.

of several riverfront structures and their associated protection works to a level that would accommodate anticipated flows. Among the structures affected was the Wharf Parking Garage (mile 90.6) (Figure 27), which is operated by the City of Wheeling and located on the left bank of the main channel of the Ohio River directly across from the center of Wheeling Island (Figure 28), and approximately 0.4 mile downstream from the historic Wheeling Suspension Bridge.

54. Unpublished discharge data available for the U. S. Weather Bureau gaging station at the Wheeling Parking Wharf are representative of the Wheeling reach. Discharge ranges for the project life (1971 to present) are 348,000 to 6,300 cfs. Discharges of 235,000 cfs or more are considered flood flows. The maximum discharge measured at the Wheeling gage occurred on 23 June 1972. Since October 1971 other flood flows have been measured on 18 and 25 February 1966; throughout the period of record there have been many other days on which the flows have approached flood stage. Stream velocities range from 0.1 to 5.9 fps. This reach is subjected to waves from passing tows. No suspended-sediment load or bed-material gradation samples have been taken in this reach. The bed gradient is 0.80 ft/mile with the channel bed material consisting of sand and gravel. The bank slopes are 1V on 2H in the vicinity of the parking facility, and the bank soils are clay, sandy clay, and silt. The depth to bedrock ranges from 15 to 25 ft (U. S. Geol Survey 1956).

55. The original bank protection at the Wheeling site consisted of 624 lin ft of a concrete slurry blanket, approximately 12 in. thick, constructed to an elevation varying between 625.5 and 626.5 ft. The date of placement of this slurry is not known. With the anticipated rise of the Hannibal Pool, ORP decided to raise the elevation of the lower level of the parking garage to 631 ft and to extend the slope protection to the 631-ft elevation.

56. In mid-1971, ORP advertised for bids to raise and resurface the lower parking level with bituminous pavement, to remove and replace the existing steel guard rail, and to place 624 lin ft of riprap bank potection in a 12-in. layer over filter fabric and granular fill

extending from the elevation of the existing concrete slurry revetment (625.5-626.5 ft) to an elevation of 631 ft. Figure 29 shows a typical section of this revetment taken from plans prepared by ORP. On 27 July 1971 the contract was awarded to the James White Construction Company of Weirton, W. Va. Work on the project began on 9 August 1971 and was completed by 20 October 1971. The total cost was $107,348.51 which included $12,342.00 for 374 yd^3 of riprap and $3,910.00 for 1,150 yd^2 of Filter-X fabric manufactured by Carthage Mills of Cincinnati, Ohio.

57. Partial failure of the revetment occurred in March 1972 (Figure 30). As a result of this failure, an inspection was conducted by ORP personnel on 29 March 1972 after the water had receded to 4 ft below the top of the original concrete slurry revetment. The investigation revealed that in many locations the 1971 protection had been placed on top of the original concrete slurry revetment with no toe support to prevent the stone from sliding downslope (Figure 31). The original contract drawings (Figure 29) clearly indicate that the new riprap should have been keyed through the surface of the existing protection as toe support. In a number of sections the riprap had slid into the river, thus exposing and often tearing the filter fabric.

58. Repair of the damaged revetment was requested on 19 June 1973 by the Engineering Division of ORP and was completed by personnel of the Operations and Maintenance Branch on 13 September 1973. Figure 32 shows a profile view of a typical secton of the repairs to the slope protection. The total cost of the 1973 repairs was $33,700 which included removal of the 1971 revetment and part of the lower bituminous pavement, purchase of filter fabric (Poly-Filter X, manufactured by Carthage Mills of Cincinnati, Ohio) and limestone riprap, entrenchment of toe stone through the original concrete slurry revetment, placement of the riprap, repaving some of the eroded bituminous pavement, and replacement of some of the bituminous pavement on the lowermost parking level with a slurry-grouted riprap. Where possible the existing filter fabric (Filter-X) was left in place; but where the fabric was damaged or missing, new fabric (Poly-Filter X) was used. The U. S. Army Engineer Division, Ohio River (ORD) selected this revetment as an existing site for monitoring as a

part of the Section 32 Program (paragraph 2).

59. In general, the fabric and stone have performed well since the 1973 repairs. The WES Section 32 Program evaluation team accompanied by ORP and ORD personnel inspected the site on 22 June 1978 and found that some of the fabric placed in 1973 had been exposed due to removal of rock but that no tears in the fabric were visible (Figure 33). The WES team also found that the bituminous pavement adjacent to the guard rail had failed in a few places (Figure 34) and that some of the 1973 stone protection had slid over the original concrete slurry and into the river (Figure 35). ORP personnel inspected the condition of the revetment on 29 Mar 1979 after subsidence of the March 1979 high water. They found there was further damage to the revetment as evidenced by Figure 36. At the time of this inspection, the fabric had been pulled away from the bank and more riprap had slid into the river.

Mississippi River at Island 40 near Memphis, Tenn. (Articulated Concrete Mattress Bonded to Filter Fabric)

60. The development of articulated concrete mattresses (ACM) began in 1914 chiefly as a result of the threatened exhaustion of convenient willow growths from which timber and brush mattresses could be constructed. The basic unit of the ACM is a slab of concrete 46-1/4 in. long by 14 in. wide by 3 in. thick. These slabs are cast on and tied together by corrosion-resistant wire to form rectangular units 4 ft wide by 25 ft long when allowance is made for the 1-in. space between the slabs and for the space between adjacent rectangles. These units are commonly called "squares" (100 ft^2). Because a mattress is made up of squares connected by articulated joints, it possesses a measure of flexibility in all directions. Thus a mattress has the capability of adjusting itself to irregularities in the bank and to scour pockets that may develop. The principal disadvantage of the concrete mattress is the possibility of bank material eroding and escaping through the interstices of the articulated joints. To mitigate this problem a gravel filter is often placed beneath the mattress.

61. Studies conducted by the U. S. Army Engineer District, Memphis

(LMM), in 1965 (Fairley et al. 1970) indicated that filter fabric was superior to gravel as a filter for the ACM revetment placed at Island 63 Bar in the Mississippi River (mile 639.5 AHP*). The revetment design included ACM extending from the thalweg, or toe of the slope, to an elevation of about +5 ALWP (5 ft above the elevation of average low-water plane). Ten-in.-thick riprap paving was placed from the inshore edge of the mattress to the top of the bank. The filter fabric was installed manually at Island 63 Bar site, but LMM found it difficult to extend the fabric to the desired water depth, especially with river stages rising during construction. LMM then attempted to determine the feasibility of using filter fabric bonded to ACM during casting operations by constructing an experimental subaqueous revetment on the right bank of the Mississippi River at Island 40 (mile 747.0 AHP), approximately 12 miles upstream from Memphis, Tenn. (Littlejohn 1977) (Figure 37).

62. The closest gaging station to Island 40 site is the CE station located at the Harahan Railroad bridge in Memphis (mile 734.8 AHP). Discharges measured during the period of record (1933 to present) are: maximum 1,980,000 cfs; mean 462,100 cfs; and minimum 19,200 cfs. In 1973, the U. S. Geological Survey (USGS) began collecting sediment samples from the Harahan Railroad bridge as part of the National Stream Quality Accounting Network. The number of samples taken in a given year has ranged from 3 to 12. Based on this limited sampling, the estimated daily suspended-sediment loads for the period of record (February 1973 to the present) are: maximum 1,119,000 tons/day; mean 248,000 tons/day; and minimum 28,000 tons/day. The estimated mean daily dissolved solids load occurring during 1973-1974 was 460,000 tons/day. The channel gradient through this reach is approximately 0.5 ft/mile; the bed is considered to be unstable. The bed and banks are composed of sandy soils (Keown et al. 1977).

63. On 22 August 1968, a CE sinking unit placed 444 squares of ACM revetment at Island 40 with fabric that was bonded to the squares during the casting operation. The fabric selected for this revetment

---

* Above Head of Passes, Mississippi River mile 0.0 (MRC 1976).

was Poly-Filter X, manufactured by Carthage Mills of Cincinnati, Ohio. The fabric was ordered in 50-in. widths so that is would extend 1-7/8 in. beyond the edge of the concrete mattress on each side. The width of a mattress square is 46-1/4 in. and the longitudinal space between adjacent in-place squares 1-3/4 in. Since the fabric on each of the two squares would extend over the space, one overlapping the other, this space was covered by two layers of filter fabric, thus providing an extra margin of safety to ensure that the fabric would extend over the full area of the mattress.

64. The placement of ACM with attached filter fabric at Island 40 required development of a method to fasten the fabric to the squares. After considering several possibilities, LMM decided to incorporate a raised seam in the fabric to form a protrusion that would be imbedded in the concrete during the casting operation. The idea was simple; however, the seam was devised within two basic constraints: (a) to protrude far enough to become firmly imbedded in the concrete; (b) to be either sufficiently small or compressible to prevent raising the steel forms excessively. Samples of fabric with two types of raised seams, located 6 in. from the longitudinal edges of the fabric strip, were supplied by the manufacturer. One type of seam consisted of a 1/8-in. hollow polyethylene cord that was sewn into a fold of the fabric. The other consisted of a double fold in the fabric sewn in place. Small-scale laboratory tests were conducted by casting individual concrete blocks to determine the bonding qualities of each seam (Figure 38). These tests indicated that the seam with the cord sewn in furnished a more satisfactory fastening capability than the seam with the double fold. Since the laboratory tests were of such limited scale, LMM decided to cast 407 squares using the cord seam and 37 squares using the double-fold seam to test both types under actual field conditions.

65. The experimental squares were cast at Richardson Landing Casting Field, Tenn., from 6-21 May 1968. The operation was conducted in conjunction with the casting contract, which was modified to incorporate the casting of 444 squares with the filter fabric bonded to the bottom side.

66. There are six steps to be completed during a normal casting operation (i.e. when no filter fabric is used), as follows:

a. Kraft paper is placed on the ground and on successive layers as the squares are cast.

b. Wire-mesh fabric is placed in the casting forms.

c. The forms are set in position on the kraft paper and the mesh positioned in the forms.

d. Concrete is poured into the forms.

e. The concrete is finished.

f. The forms are removed after the initial set of the concrete, completing the fabrication.

The squares are cast in stacks 12 units high with the ends of the stacks normally spaced 10 in. apart. The casting of the experimental squares required a slight alteration of the normal procedure to include two additional steps. After the kraft paper was positioned, the filter fabric was placed on top of the paper with the seams on the top side (Figure 39). The fabric was supplied in rolls 470 and 495 ft long, and placed in continuous runs to cover 18 and 19 stacks, respectively, for a complete row of 37 stacks. This required that the fabric between the ends of the stacks be cut after the concrete had set (Figure 40). The mattress stacks were spaced 5 in. apart at the ends rather than the usual 10 in. to minimize waste of the filter fabric. The fabric was cut nearly flush with the ends of the concrete slabs to prevent the excess fabric from interfering with tying the three wires at the ends of the slabs during assembly of the mattress. Since the maximum space between the ends of the slabs after assembly is only 1/2 in., this did not materially affect the filter coverage.

67. The Island 40 site had a sandy bank that was highly susceptible to leaching. The revetment design extended from a depth of 35 ft below the ALWP (the toe of the slope), to about 5 ft above the ALWP, for an inshore to outshore width of about 275 ft. A gravel blanket was extended from +15 ALWP, or approximately midbank, down the slope to a point 10 ft vertically below the water surface. The test squares were placed in two mattresses as part of the 2320-ft upstream extension of the revetment (Figure 41). One full mattress, 135 ft by 275 ft, was

assembled from 385 of the test squares. The remaining 59 squares were placed in the first two launches, or the inshore 50 ft, of the next mattress upstream. The sinking operation proceeded without difficulty after the crane operators became accustomed to handling the experimental mattress. After this operation was completed, riprap stone paving was placed from the inshore edge of the mattress to the top of the bank.

68. The assembly of the test squares into a mattress was done in the same manner as with standard mattress squares. Most of the wire tying was done manually (the standard method for tying prior to 1970) and proceeded at a normal rate. One automatic tying tool (Figure 42) was being tested in a separate experiment to determine its feasibility for use in lieu of manual tying. This device was used successfully in tying some of the test squares, with no malfunctions or delays due to interference of the underlying filter fabric extending beyond the sides of the squares. LMM closely observed each launch as it moved down the mat deck and into the water to determine whether the filter fabric remained bonded to the bottom of the mattress squares (Figure 43). The fabric on seven squares was pulled loose from the concrete mattress, and a few more squares had portions of the fabric pulled loose to the extent that the subaqueous filter coverage was questionable.

69. LMM had some concern that sinking the experimental mattress might present a problem because of the substantial reduction in permeability of the mattress due to the attached filter fabric. There have been instances where a standard mattress has been overturned during the sinking operations by the tremendous forces of the current; however, LMM experienced no difficulty, and the experimental mattress sank as smoothly as standard mattress. Surface velocities of the current measured at the inshore and outshore ends of the mattress were 3.9 and 4.7 fps, respectively, generally representing normal flow conditions.

70. This means of placing ACM with filter fabric on an underwater subgrade only involved a simple alteration of the existing casting method. Thus, the only additional cost was the amount required for the purchase and installation of the fabric during the casting operation. No additional costs were incurred for sinking because there was no

difference in the handling, assembling, and launching of the experimental mattress as compared with a standard mattress. The in-place cost (1968) of the mattress with the fabric attached amounted to $13.79/square with the additional cost for casting the square with the filter fabric attached being about $0.10/square.

71. The great majority of the test squares were cast and placed in a satisfactory condition, with no unusual problems being encountered. Casting the squares with the filter fabric attached to the bottom side and sinking them as an integral part of a mattress is a means by which revetments can be constructed to provide a greater degree of protection against erosive forces. This method also allows placement of fabric to at least a depth of 35 ft; placement to greater depths may be possible but this can be determined only by further tests.

72. As a result of the LMM study, the placement of filter fabric over the entire mattress area can be considered practical from a construction standpoint and can be considered economically feasible. At locations where problems with bank failures are anticipated because of severe current attack, highly erodible soils, or other adverse conditions, the extra degree of protection provided by the filter fabric may be warranted. LMM indicates that the reduction in maintenance costs would in many cases be substantial enough to more than offset the additional cost of the filter fabric depending on individual site conditions.

Little Rockfish Creek at Hope Mills, N. C. (Gabions on Filter Fabric)

73. Little Rockfish Creek rises 18.2 miles northwest of Hope Mills, N. C., and flows in a southwesterly direction through Hope Mills to its confluence with Rockfish Creek, approximately 1 mile southeast of the municipality limits. The stream drains an area of 95.6 square miles, which includes a portion of the Fort Bragg Military Reservation. The only major hydraulic control on the creek is a dam constructed by Dixie Yarn Mills Textile Co., immediately upstream from Hope Mills (Figure 44). This structure impounds a multiple-purpose reservoir with a design storage capacity of 110 acre-ft. The reservoir provides the

textile company with water for fire protection and for operation of an emergency generator; in addition, it affords recreation to the local populace.

74. Flows have not been measured on a regular basis in Little Rockfish Creek. The USGS recorded discharges from May-September 1978 and reported to the U. S. Army Engineer District, Wilmington (SAW) that they ranged from 83 to 1179 cfs. The upstream dam (Figure 45) exerts some influence over streamflows. Additional measurements made by the USGS included flow velocity distributions (5 and 18 Apr 1978), which ranged from -0.75 to 3.68 fps (negative sign indicates upstream flow). No information is available on sediment loads. The bed gradient through this reach is 21 ft/mile; the bank slopes are 1V on 1.5H. The upper soil layer of the bank material (10 to 12 ft) is medium sand (SP-SM); and the next 30 ft, stiff sandy clay (CH).

75. Prior to 1972, serious streambank erosion had been experienced on the cut bank in the bend below the dam (Figure 44). Local officials felt that continued erosion would eventually cause not only a washout of East Patterson Street but also the loss of town-owned utilities, a 6-in. sewerline, and a 2-in. waterline located beneath the street. Heavy rains during 1972-1973 caused abnormally high stages and correspondingly high velocities in Little Rockfish Creek which resulted in the loss of protective vegetative cover (Figures 46 and 47). The town of Hope Mills attempted to retard the failure of the streambank by dumping broken concrete rubble on the slope (Figure 48), but this did not prove to be a successful method to minimize the erosion.

76. In response to a request from the Mayor of Hope Mills (dated 9 June 1972), SAW prepared a report (Wilmington District 1974) presenting the results of an investigation of the erosion occurring downstream from the dam. The report contained recommendations for protection of the eroding streambank and showed that an installation of gabions on filter fabric would be more economical than either a 30-in. layer of riprap placed on filter fabric or the excavation of a new channel. In addition, the SAW study indicated that without protection a 225-ft section of East Patterson Street would be washed out a minimum of three

times during a 50-yr evaluation period, but that with protection, a benefit-cost ratio of 1.1 to 1 would be realized.

77. Under the authority of Section 14 of the 1946 Flood Control Act SAW constructed a revetment on Little Rockfish Creek (Figure 49) consisting of gabions (manufactured by Maccaferri Gabions, Inc., of Williamsport, Md.) placed on filter fabric (Poly-Filter X, manufactured by Carthage Mills of Cincinnati, Ohio) with fescue and rye grass planted on the bank slopes landward of the gabions. The bank paving consisted of two 1-ft by 3-ft by 12-ft gabion sections placed perpendicular to the streamflow, and a 3-ft by 3-ft by 12-ft gabion section placed parallel to the flow with a 1-ft by 6-ft by 12-ft gabion support apron at the toe of the slope (Figures 50 and 51). The contractor filled the gabions with 3- to 6-in.-diam stones. The total length of the completed gabion revetment is approximately 300 ft with the gabions and filter fabric extending 15 ft above the streambed elevation. The material used for fill was silty sand (SM). The installation was completed in May 1976 at a cost of $105,000. The Little Rockfish Creek bank protection works was selected as an existing site in the U. S. Army Engineer Division, South Atlantic, to be monitored under the auspices of the Section 32 Program (paragraph 2).

78. SAW indicates that there was no formal preconstruction subsurface investigation. During construction, the contractor encountered a perched water table resulting in saturation of the construction fill material. In January 1977, approximately 20 lin ft of the revetment slipped 6 to 8 ft vertically. The suspected cause of this failure was groundwater seepage and possibly improper compaction of the fill material beneath the filter fabric, rather than high streamflows or clogging of the filter fabric.* Had a subsurface investigation been conducted prior to construction of the revetment, the perched water table condition would have been discovered, and measures to divert the groundwater away from the streambank could have been incorporated into the project design.*

---

* Unpublished file information provided by the U. S. Army Engineer District, Wilmington, CE.

Repairs to the damaged portion of the revetment were made in November 1977 (Figures 52 and 53). On 8 May 1978, SAW personnel inspected the repaired section and found no evidence of additional failure. SAW feels that the revetment has performed well; however, the site should continue to be monitored. The monitoring program being conducted by SAW under the Section 32 Program includes taking photographs of the revetment on a quarterly basis and the collection of continuous stage-discharge data using a temporary gage placed by the USGS at this site. Monitoring of the revetment is anticipated to continue through 1983.

Red River at Morameal Revetment near Shreveport, La. (Precast Cellular Blocks Hand-Placed on Filter Fabric)

79. The Morameal Revetment was placed as part of the Red River Waterway Project (New Orleans District 1977) authorized by the River and Harbor Act of 18 August 1968 in accordance with House Document 304, 90th Congress, 2nd Session. The project provides in part for a 9-ft stabilized navigation channel extending from the Mississippi River through Old River and Red River to the vicinity of Shreveport and then through Twelvemile and Cypress Bayous to a turning basin in the Lake O' The Pines (Ferrells Bridge Reservoir) near Daingerfield, Texas (New Orleans District 1972). Eight locks and dams will provide the required depths for navigation. The project also makes provisions for the extensive use of channel stabilization structures of which the Morameal Revetment is a part.

80. The Morameal Revetment is located on the left bank of the Red River 20 miles downstream from Shreveport in Bossier Parish, La. (Figure 54). The bank protection works were constructed by the U. S. Army Engineer District, New Orleans (LMN), as an experimental revetment using the conventional trenchfill design section; however, other materials were used for bank pavement in addition to standard stone. The revetment was placed in seven test sections, each having a 1V-on-3H upper bank slope with the bank being paved from the toe of the upper bank slope to the 140-ft elevation contour (New Orleans District 1974). The downstream end of the revetment begins at mile 256.6, left bank, and extends

upstream 7100 ft. Several different types of bank protection were used at the Morameal site, including riprap, rock and wire mattresses, sand-filled acrylic bags (also called acrilan sand pillows), soil-cement blocks, and precast cellular blocks. This case history will concentrate on the 1500-ft Section C, precast cellular blocks placed on the filter fabric from mile 257.19 to mile 257.48. A detailed discussion of the various other types of bank protection used at the Morameal Revetment is provided by Keown and Dardeau (1979).

81. No discharge or sediment data are available at the Morameal site; however, discharge and suspended-sediment data are available for the gaging station at Shreveport (miles 277.6 and 277.8, respectively). The discharge passing Shreveport is somewhat regulated by Denison Dam (closed 1943), Texarkana Dam (closed 1956), and Millwood Dam (closed 16 August 1966). The discharges of record (from 1928) prior to 16 August 1966 are: maximum 303,000 cfs, and minimum 690 cfs. (No mean discharge value is available for the period prior to 16 August 1966.) After 16 August 1966, the discharges of record (to the present) are: maximum 165,000 cfs; mean 26,100 cfs; and minimum 1,600 cfs. Suspended sediment samples have been taken by LMN at mile 277.8 since 1966; however, the data have not been published (Keown et al. 1977). The bank material in the vicinity of the Morameal Revetment is a lean clay with a trace of sand; the bed material consists of medium and fine sands. The existing gradient through this reach is 1.1 ft/mile; in addition, the most recent hydrographic survey (New Orelans District 1970) indicates that the thalweg varies from an elevation of 98 to 110 ft.

82. In the 1500 ft of the Morameal Revetment designated as Section C, precast cellular blocks (Gobi Blocks, manufactured by ERCO Systems, Inc., of New Orleans, Louisiana) were placed (Figure 55) on Poly-Filter X filter fabric (manufactured by Carthage Mills of Cincinnati, Ohio) to an elevation of 140 ft (May-August 1975). Figure 56 shows the block dimensions, and Figure 57 is a typical cross-sectional drawing of block implacement. The Gobi Blocks were hand-placed on the filter fabric and butted together for continuous coverage. During the installation, heavy rains and rising river stages hampered work. In

some portions of this section, overbank drainage and/or groundwater, flowed between the filter fabric and bank resulting in a buildup of material between the fabric and bank perhaps due to inadequate subsurface drainage, clogging of the fabric, or subsidence of surrounding blocks. This action caused bulging of the overlying fabric and blocks, and necessitated replacement of fabric and repositioning of the blocks in several areas. The upper edge of the filter fabric was buried to minimize the piping of material under the fabric due to overbank flow. A total of 444.44 squares of the precast cellular blocks were placed on the filter fabric at a cost (1974) of $111,000. This figure excludes the cost of site preparation and the cost of riprap used in the toe trench.

83. The Morameal Revetment was selected by the U. S. Army Engineer Division, Lower Mississippi Valley, for monitoring as an existing site under the auspices of the Section 32 Program (paragraph 2). On 9 May 1978 the WES Section 32 Program evaluation team accompanied by LMN personnel inspected the condition of the Morameal Revetment. The filter fabric was not visible through most of this section because of deposition and the growth of vegetation. Figure 58 shows the general appearance of the revetment section. At the few locations where the filter fabric was visible, it seemed to be in good condition (Figure 59). Overbank drainage has removed some of the protective soil covering the fabric at the landward edge of the section (Figure 60); piping beneath the fabric was also noted at several locations (Figure 61).

Tangipahoa River near Independence, La. (Precast Cellular Blocks Bonded to Carrier Fabric)

84. In 1953, the Southern Natural Gas Company (S.N.G. Co.) installed a 20-in. pipeline (Duck Lake - Franklinton Main Line) to transport natural gas from its reserves in St. Mary Parish, La., to market areas in the southeastern United States.* By the late 1960's, it became apparent that a greater pipeline capacity was needed to handle the

* Unpublished file information provided by Southern Natural Gas Co., Birmingham, Ala.

additional gas reserves that had become available since 1953. In 1969, a 30-in. loop pipeline was laid parallel to the existing 20-in. line. Both of these pipelines cross the Tangipahoa River near Independence in Tangipahoa Parish, La., at mile 38.9 (about 50 miles northwest of New Orleans; Figure 62).

85. The nearest gaging station to the pipeline crossings is operated by the USGS at Robert, La. (mile 22.5). Discharges measured during the period of record (1938 to present) are: maximum 50,500 cfs; mean 1,100 cfs; and minimum 245 cfs. No data are available on suspended-sediment loads or bed and bank material through this reach; however, sand has been noted in the channel and the banks appear to be mostly fines. The bed gradient for the reach that includes the pipeline crossings is approximately 2.9 ft/mile.

86. A serious bank erosion problem did not exist through this reach when the first pipeline was placed across the Tangipahoa River; however, in the early 1960's, before construction of the 30-in. pipeline, erosion began to work downstream along the left (east) bank toward the pipeline crossing. By the early 1970's, the eroded bank was only 1200-1500 ft upstream. This bank erosion was later aggravated by flooding in December 1971 and May 1972, which exposed the 20-in. line with considerable loss of bank material.*

87. These two pipelines are of prime importance to S.N.G. Co. because they collectively transport natural gas to an area that represents 35 percent of their distribution system. In 1973, S.N.G. Co. attempted to check the bank erosion by placing a permeable jetty system, consisting of 36 Henson Permeable Spur Jetties (manufactured and installed by Hold-That-River Engineering Co. of Houston, Tex.) positioned along the left bank transverse to the flow and extending upstream and down stream from the pipeline crossings (Figure 63). The system, which was featured in the Oil and Gas Journal (O'Donnell 1973), performed

---

* Personal communication from T. H. Knott, Division Superintendent, Southern Division, Southern Natural Gas Company, Chalmette, La., dated 31 Jan 1979, to E. A. Dardeau, Jr., WES.

adequately even to the point of accumulating debris and inducing sediment deposition until additional flooding caused flanking on the landward side of the jetties. As a stop-gap erosion-control measure, S.N.G. Co. placed cement-sack revetment on the eroded bank in September 1974; however, the erosion continued and began working behind the upper edge of the bags (Figure 64).

88. S.N.G. Co. sought an economical yet effective means of protecting the eroding bank. Site conditions and the frequency of storm events in the Tangipahoa River Basin necessitated that the method used be one that could be implemented with relative ease and in a reasonable length of time. The method preferred by S.N.G. Co. and the one to which approval was granted by the various local, State, and Federal authorities involved the placement of 284 4-ft by 16-ft mats, and 32 4-ft by 18-ft mats which consisted of precast cellular blocks bonded to filter fabric. These mats, called Gobimats (manufactured by ERCO Systems, Inc., of New Orleans, La., and marketed by Erosion Control Systems, Inc., of Metairie, La.) were made by bonding Gobi Blocks (Figure 56) to Nicolon 66511 fabric (manufactured by Nicolon Corp. of Baton Rouge, La.).*

89. Prior to construction, the bank was graded to a 1V-on-2H slope. Redistribution of approximately 1,300 yd^3 of bank material was necessary in order to achieve this grade. Each mat was constructed so that it had an additional 1 ft of fabric extending beyond the two shorter sides and one of the longer sides, so that the actual size of the fabric sheets used to make the 16-ft long Gobimats was 5 ft by 18 ft, and that used to make the 18-ft long Gobimats was 5 ft by 20 ft. This extra material allowed the Gobimats to be lifted by the fabric during placement with a mobile crane (Figures 8 and 65) and provided for continuous filter coverage between the individual mats.

90. Three vertical rows of Gobimats were placed along the left bank of the Tangipahoa River extending from approximately 150 ft to 600 ft upstream from the pipeline crossings. A total of 20,480 ft^2 of

---

* Unpublished file information provided by Erosion Control Systems, Inc., Metairie, La., and by ERCO Systems, Inc., New Orleans, La.

the mats was used. Beneath the row of mats nearest the edge of the water, S.N.G. Co. placed an additional layer of Polyfelt TS-300 filter fabric (manufactured by Chemie-Linz of Linz, Austria, and distributed by Bradley Materials of Valparaiso, Fla.). This material was used to provide the added filtration necessary for the fines present on the lower bank.* Installation of the revetment was completed in April 1978 at a cost of $55,000, including material, freight, and supervision by Erosion Control Systems, Inc. Figure 65 shows the construction operation, and Figure 66 shows the completed installation as it appeared in early May 1978.

91. The upstream edge of the Gobimat revetment was placed in a trench, and Chance Screw Anchors (manufactured by Allen Street of Centralia, Mo.) were installed in the trench through the leading edge of the Gobimat at 4-ft intervals. The anchors were then connected with a continuous steel rod through each anchor "eye," and the rods were welded to the anchors, thereby providing a continuous tie-down of the edge. The trench was then backfilled. The landward and riverward edges of the Gobimat installation were keyed with trenches and covered with soil fill. The disturbed area landward of the top bank was fertilized and seeded with native grasses that soon became established.

92. In May 1978 approximately three weeks after the installation was completed, a storm event tested the effectiveness of the revetment. A later inspection indicated that no failures had occurred and the filter fabric overlap remained continuous between the mats. S.N.G. Co. indicates that it has been pleased with the performance of the revetment thus far.

---

* Gobimats are now manufactured using the finer-weave filter fabric, Nicolon 70, so that the extra layer of filter is no longer necessary for similar soil conditions.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

93. Properly selected and placed filter fabric may be considered as a substitute for part or all of a granular filter under revetment for situations where granular filter bedding materials are not available or cost-effective due to transportation, quality control, or manpower constraints. The most common use for filter fabric in streambank protection has been for placement beneath stone riprap; however, some use has been realized as a substitute for a granular filter below articulated concrete mattresses, gabions, and precast cellular blocks. The fabric has also been used as a carrier fabric for precast cellular blocks (attached to the fabric with adhesive material) and as a support for a dike or jetty. Minor usage of filter fabric has been reported as container material for sack revetment.

94. Laboratory testing indicates that properly selected filter fabrics can perform at least as well as conventional granular filters for a number of applications. Additional studies have shown that woven fabrics are considerably stronger in uniaxial tension than nonwoven fabrics (Haliburton et al. 1978). Cost studies have indicated that filter fabric is competitive with granular filters on a short-term basis (Fairley et al. 1970).

95. The use and placement of filter fabric as discussed herein indicate that more care and precautions are required than with graded granular filters. In comparison with graded granular filters, fabric material is relatively new (less than 25 years of experience). Caution is advised on the use of filter fabrics in lieu of graded granular filters beneath revetments subject to turbulent flow. Additional revetment thickness may be required to keep the fabric in a low turbulence environment free of adverse and fluctuating pressures. Filter fabrics should not be used in lieu of granular filters on soils having more than 85 percent of material by weight passing the No. 200 sieve or in high energy environments.

Recommendations

96. More research and prototype comparisons of filter fabric versus granular filters would benefit the designers of embankment protection subject to turbulence, waves, and rapid drawdown.

97. The recommendations and general guidance given in the CE specifications (OCE CW 02215 1977) should be followed in the selection and placement of a specific filter fabric for a given project application.

98. CE civil works construction guide specifications concerning the use of filter fabric as a substitute for granular filters should be expanded to cover its use with revetment materials other than riprap and to include long-life fabrics other than those manufactured from plastic yarns; in addition, guidelines are needed to specifically evaluate nonwoven fabrics.

REFERENCES

Calhoun, C. C., Jr. 1969 (Oct). "Summary of Information from Questionnaires on Uses of Filter Cloths in the Corps of Engineers," Miscellaneous Paper S-69-46, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

__________. 1970 (Jan). "Interim Report; Investigation of Plastic Filter Cloths," Miscellaneous Paper S-70-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

__________. 1972 (Jun). "Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths," Technical Report S-72-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Dallaire, G. 1977 (Mar). "Filter Fabrics Can Cut Costs of River-Bank and Shore-Protection Structures," Civil Engineering, Vol 47, No. 3, pp 74-79.

Fairley, J. G., et al. 1970 (Jun). "Use of Plastic Filter Cloth in Revetment Construction," Potamology Investigations Report 21-4, U. S. Army Engineer District, Memphis, CE, Memphis, Tenn.

Giroud, J.-P., Girouc, J.-P., and Bally, F. 1977 (Aug). "Behavior of a Nonwoven Fabric in an Earth Dam," University of Grenoble, Grenoble, France; translated from French by Ralph McElroy Co., Custom Division, Austin, Tex.

Haliburton, T. A., Anglin, C. C., and Lawmaster, J. D. 1978 (May). "Selection of Geotechnical Fabrics for Embankment Reinforcement," U. S. Army Engineer District, Mobile, CE, Mobile, Ala.; prepared by Oklahoma State University, Department of Civil Engineering, Stillwater, Okla., under Contract DACW 01-78-C-005.

Headquarters, Department of the Army, Office, Chief of Engineers. 1969. "Report of the Chief of Engineers to the Secretary of the Army on a Study of Streambank Erosion in the United States," Washington, D. C.; prepared for the U. S. House of Representatives, Committee on Public Works.

__________. 1971 (Aug). "Report on the National Shoreline Study," Washington, D. C.

__________. 1973 (May). "Guide Specifications, Civil Works Construction, Plastic Filter Cloth," CE-1310 (Superseded by CW 02215), Washington, D. C.

__________. 1977 (Nov). "Civil Works Construction, Guide Specification, Plastic Filter Fabric," CW 02215 (Supersedes Oct 1975 specification), Washington, D. C.

Keown, M. P., Dardeau, E. A., Jr., and Kennedy, J. F. 1977 (Mar). "Inventory of Sediment Sample Collection Stations in the Mississippi River Basin," Technical Report M-77-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Keown, M. P., et al. 1977 (May). "Literature Survey and Preliminary Evaluation of Streambank Protection Methods," Technical Report H-77-9, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Keown, M. P., and Dardeau, E. A., Jr. 1979 (Jun). "Section 32 Program, Streambank Erosion Control Evaluation and Demonstration, Work Unit 2, Evaluation of Existing Bank Protection; Field Inspection of Morameal Revetment on the Red River," Inspection Report 7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Klassen, E. W. 1976. "Synthetic Fabrics in Civil and Hydraulic Engineering," Engineering Digest, Vol 22, No. 4; reprinted by Staff Industries, Inc., Detroit, Mich., as Information Service Bulletin No. 093077.

List, H. J. 1977 (Apr). "Woven and Nonwoven Fabric Filters in Waterways Engineering - Tests and Dimensioning," Proceedings, International Conference on the Use of Fabrics in Geotechnics, Association Amicale des Ingenieurs, Anciens Eleves de l'E.N.P.C., Paris, pp 339-344.

Littlejohn, B. J. 1977 (Aug). "Use of Plastic Filter Cloth in Revetment Construction, Follow-up Study," Potamology Investigations Report 21-5, U. S. Army Engineer District, Memphis, CE, Memphis, Tenn.

Marks, B. D. 1975. "The Behavior of Aggregate and Fabric Filters in Subdrainage Applications," University of Tennessee, Knoxville, Tenn.

Mississippi River Commission, CE. 1976. "Flood Control and Navigation Maps of the Mississippi River, Cairo, Illinois, to the Gulf of Mexico," 44th ed., Vicksburg, Miss.

O'Donnell, J. P. 1973 (8 Jan). "Permeable Spur Jetties Protect Pipeline Crossings," The Oil and Gas Journal, pp 100-103.

Office, Chief of Engineers, Department of the Army. 1978 (31 Mar). "Engineering and Design; Design and Construction of Levees," Engineer Manual 1110-2-1913, Washington, D. C.

Steward, J. E., Williamson, R., and Mohney, J. 1977 (Jun). "Guidelines for Use of Fabrics in Construction and Maintenance of Low Volume Roads," U. S. Department of Agriculture, Forest Service, Portland, Oreg.; Reprinted 1978 by U. S. Department of Transportation, Federal Highway Administration, Office of Research and Development, as Report No. FHWA-TS-78-205.

U. S. Army Engineer District, New Orleans, CE. 1970 (Mar). "Red River Hydrographic Survey," Vol 1, New Orleans, La.

__________. 1972 (May). "Red River Waterway, Louisiana, Texas, Arkansas, Oklahoma; Stabilization and Cutoffs," Design Memorandum No. 1, New Orleans, La.

__________. 1974 (3 May). "Specifications for Red River, Morameal, Bossier Parish, La., Experimental Revetment, Item R-257.0-L (1967 Mileage)," Solicitation No. DACW29-74-B0300, New Orleans, La.

__________. 1977 (1 Nov). "Project Maps; Vol 1, Rivers and Harbors," New Orleans, La.

U. S. Army Engineer District, Pittsburgh, CE. 1975 (Jan). "Ohio River Navigation Charts, Pittsburgh, Pa., to New Martinsville, W. Va.," Pittsburgh, Pa.

U. S. Army Engineer District, Wilmington, CE. 1974 (Jul). "Report on Little Rockfish Creek, Hope Mills, North Carolina," Wilmington, N. C.

U. S. Geological Survey, State of West Virginia. 1956 (1 Dec). "Geology and Economic Resources of the Ohio River Valley in West Virginia; Ground-Water Resources of the Ohio River Valley in West Virginia," Vol 22, Morgantown, W. Va.

Table 1

History of Early Utilization of Filter Fabric for Coastal and Streambank Applications

1956 -	Dutch engineers field-tested experimental woven synthetic filter fabric as part of the North Sea Protection Project. This activity led to the formation of the Nicolon Company Erosion Control Operations.*
1958 -	Filter fabric was first used in the United States under interlocking block revetment in Florida. As a result of this project, Carthage Mills of Cincinnati, Ohio, began to market woven synthetic filter fabric (Dallaire 1977). It was during this time period that synthetic filter fabric became widely known as plastic filter cloth, probably because of the petrochemical base and weaving process used for fabrication; however, all filter fabrics are not petrochemical in origin, and all fabrics are not cloth (i.e. woven). During this same year, synthetic fabric was first used in Europe as a filter at the Onrustplaat Dam, Holland.
1962 -	Filter fabric was first used by the CE in the U. S. Army Engineer District, Memphis, as part of a riprap revetment repair project near the Madison-Marianna Bridge (Calhoun 1969). Filter fabric was also used later the same year in the U. S. Army Engineer Districts, Kansas City and St. Paul.
1963 -	Filter fabric was first used in Canada at the Metropolitan Toronto Parks Dept. dock on Centre Island (Klassen 1976). Filter fabric was first used under gabions at Chippewa National Forest, Minn.
1964 -	Filter fabric was first used by the U. S. Army Engineer District, Vicksburg, Wasp Lake to Marksville (outfall).
1969 -	Filter fabric was first used by the U. S. Army Engineer District, New Orleans, at Holly Beach, La. (Calhoun 1969). Filter fabric was also used the same year by the U. S. Army Engineer District, Tulsa, under riprap slopes and as bottom protection on the Kaw Dam project near Ponca City, Okla.
1970 -	Nonwoven filter fabric was first used as part of the Valcros Dam project in France (Giroud et al. 1977).

* B. Snaphaan, Nicolon B-V technische-en industriele weefels, Enschede, Netherlands, personal communication to Dr. J. R. Rogers, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., dated 23 Aug 1978.

Table 2

Material Costs of Selected Woven Filter Fabric

Manufacturer or Distributor	Product Name	EOS* Sieve No.	Cost/sq ft (1978 Estimate) Small Quantities (10,000 sq ft)	Cost/sq ft (1978 Estimate) Large Quantities (>1 Million sq ft)
1. Advanced Construction Specialties	(Laurel Erosion Control Cloth I)	100	$0.15	$0.102
	(Laurel Erosion Control Cloth II)	30-50	0.22	0.18
2. Carthage Mills	Filter-X	100	0.255	0.20
	Poly-Filter X	70	0.17	0.12
	Poly-Filter GB	40	0.245	0.185
3. Koch Brothers, Inc.	Zenith		0.139**	
4. Nicolon Corp.	Nicolon 70	70	0.12**	
	Nicolon 40	40	0.12**	
5. J. P. Stevens, (Menardi-Southern)	Monofilter 40	40	0.10**	
	Monofilter 70	70	0.10**	
	Monofilter 100	100	0.10**	

* Equivalent Opening Size.

** Manufacturer does not distinguish between cost categories for small and large quantities.

Table 3

Material Costs of Selected Nonwoven Filter Fabric

Manufacturer or Distributor	Product Name	Comment*	Cost/sq ft (1978 Estimate)
1. Celanese Fibers	Mirafi 140		$0.07
2. Dupont	Typar 3401	Pervious	0.08
	Typar T063	Impervious	0.155
3. Monsanto Textiles Co.	Bidim C-22		0.07
	Bidim C-34		0.124
4. Phillips Fibers Corp.	Supac 4P		
	Supac 5P	140 Sieve EOS	0.067
	Supac (New)	80 Sieve EOS	
5. Terrafix Erosion Control Products, Inc.	Terrafix 300N		0.04
	Terrafix 500N		0.55
	Terrafix 750B		0.37
	Terrafix 370RS		0.30

* Most nonwoven manufacturers prefer performance flow tests over the Equivalent Opening Size (EOS) sieve tests used for comparison with woven fabrics (see PART III).

Table 4

Physical Strength Requirements for Woven and Nonwoven Plastic Filter Fabric

Physical Property	Test Procedure	Acceptable Test Results*
Tensile Strength (unaged fabric**)	ASTM D 1682 Grab Test Method using 1-in. square jaws and a travel rate of 12 in. per minute	200-lb minimum in any principal direction
Puncture Strength (unaged fabric**)	ASTM D 751 Tension Testing Machine with Ring Clamp; steel ball replaced with a 5/16-in.-diam solid steel cylinder with a hemispherical tip centered within the ring clamp	80-lb minimum
Abrasion Resistance	ASTM D 1682 as above, after abraded as in ASTM D 1175† Rotary Platform, Double Head Method; rubber-base abrasive wheels equal to CS-17 "Calibrase" by Taber Instrument Co.; 1 kilogram load per wheel; 1000 revolutions	55-lb minimum in any principal direction

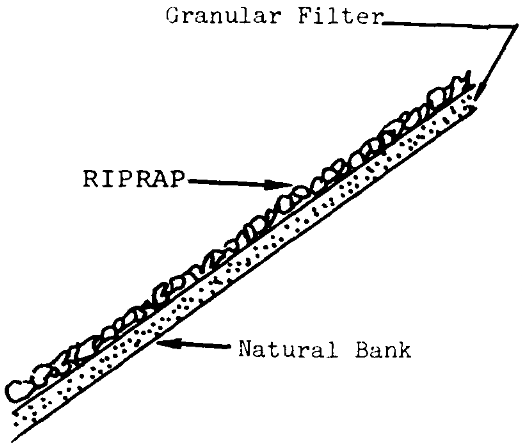
* Acceptable test results strengths may be reduced 50 percent for fabric to be used in drainage trenches, beneath concrete slabs, or to be cushioned from rock placement by a layer of sand or by zero drop height placement.

** Unaged fabric is defined as fabric in the condition received from the manufacturer or distributor.

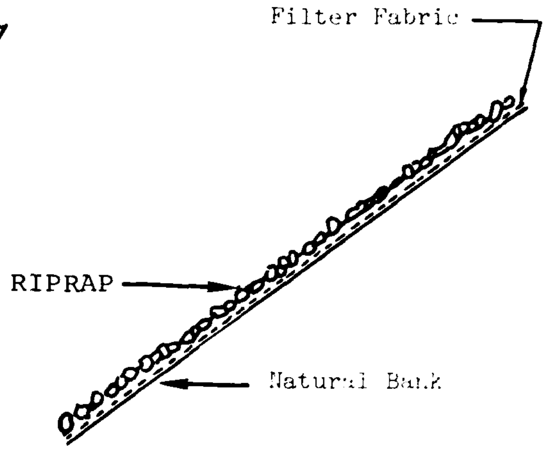
† Currently under revision (1979).

Figure 1. Sandbags made from filter fabric material were placed with a dragline near Pluimpot, Netherlands, in 1956 as part of a project to construct a dam closing off a sea inlet. This placement represents the first known use of man-made fibers as a component of a major hydraulic structure (photograph courtesy of Nicolon Corporation)

Figure 2. Filter fabric sandbags being placed near Pluimpot, Netherlands, in 1956 (photograph courtesy of Nicolon Corporation)



a. Granular filter design



b. Filter fabric design

Figure 3. Granular filter and filter fabric placed beneath riprap blanket

Figure 4. Placement of riprap on filter fabric

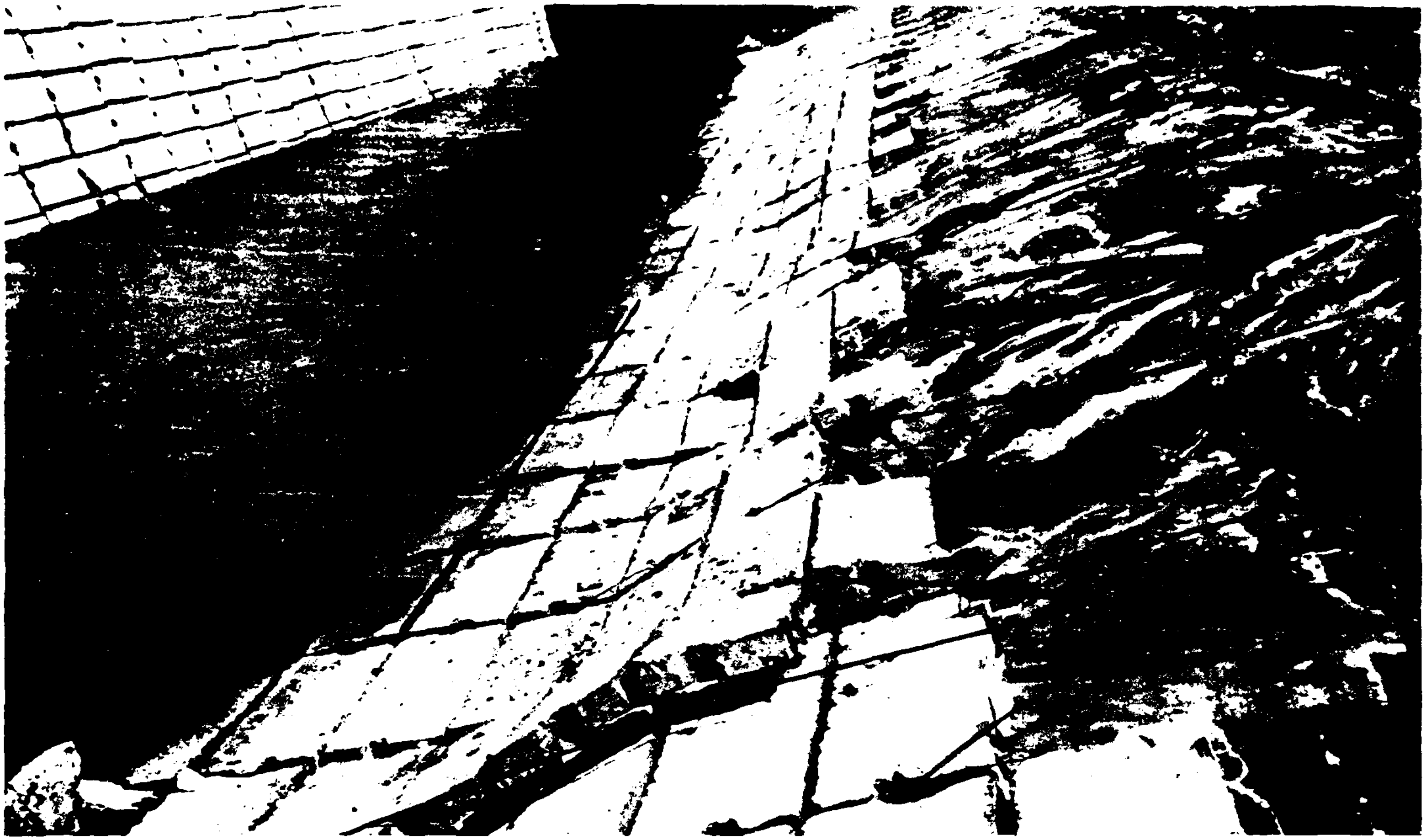


Figure 5. Articulated concrete mattress being placed over filter fabric; sinking unit is to the left

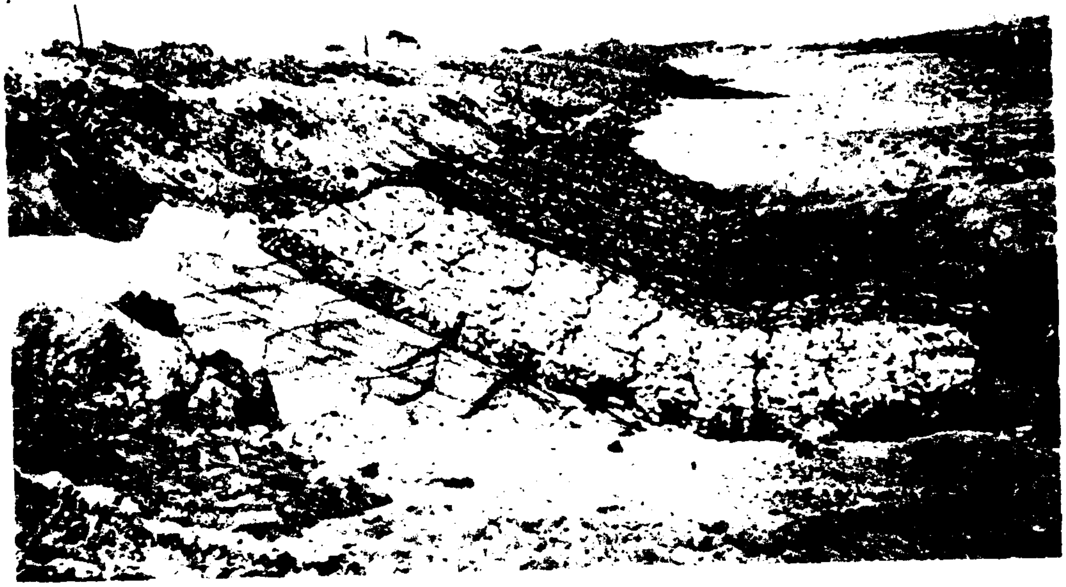


Figure 6. Placement of gabions on filter fabric (photograph courtesy of Celanese Fibers Marketing Co.)

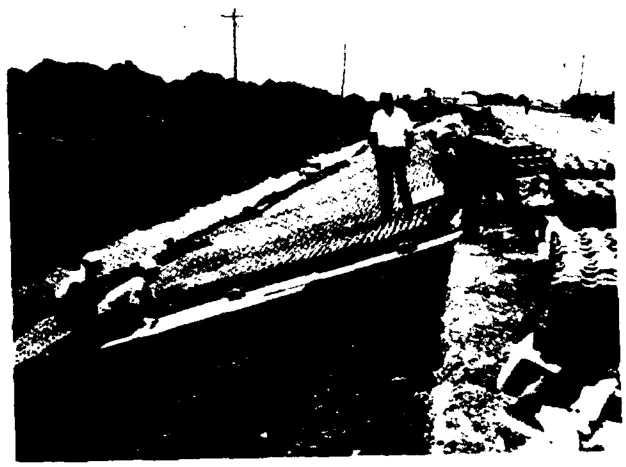


Figure 7. Hand-placement of precast concrete blocks on filter fabric (photograph courtesy of EROC Systems, Inc.)

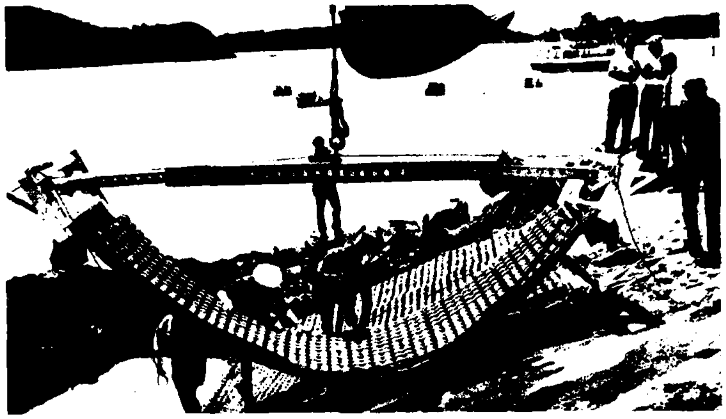


Figure 8. Mobile crane lowers carrier fabric mat onto bank. The mat is constructed by attaching precast blocks to a carrier fabric with adhesive. The completed mat is then placed at the project site (photograph courtesy of ERCO Systems, Inc.)

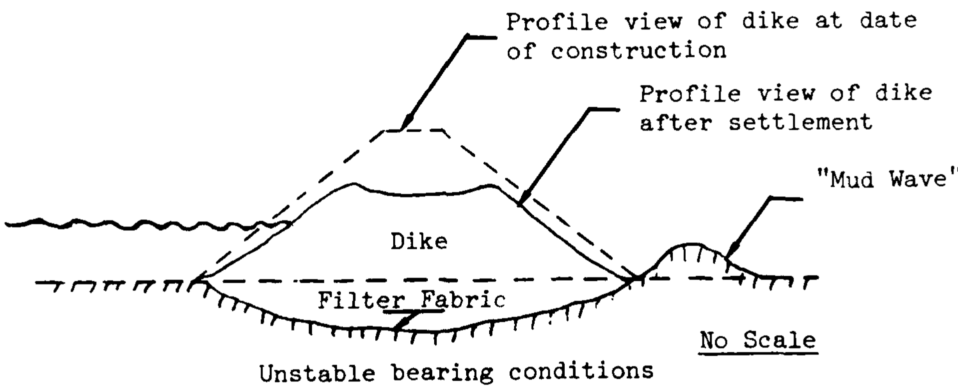
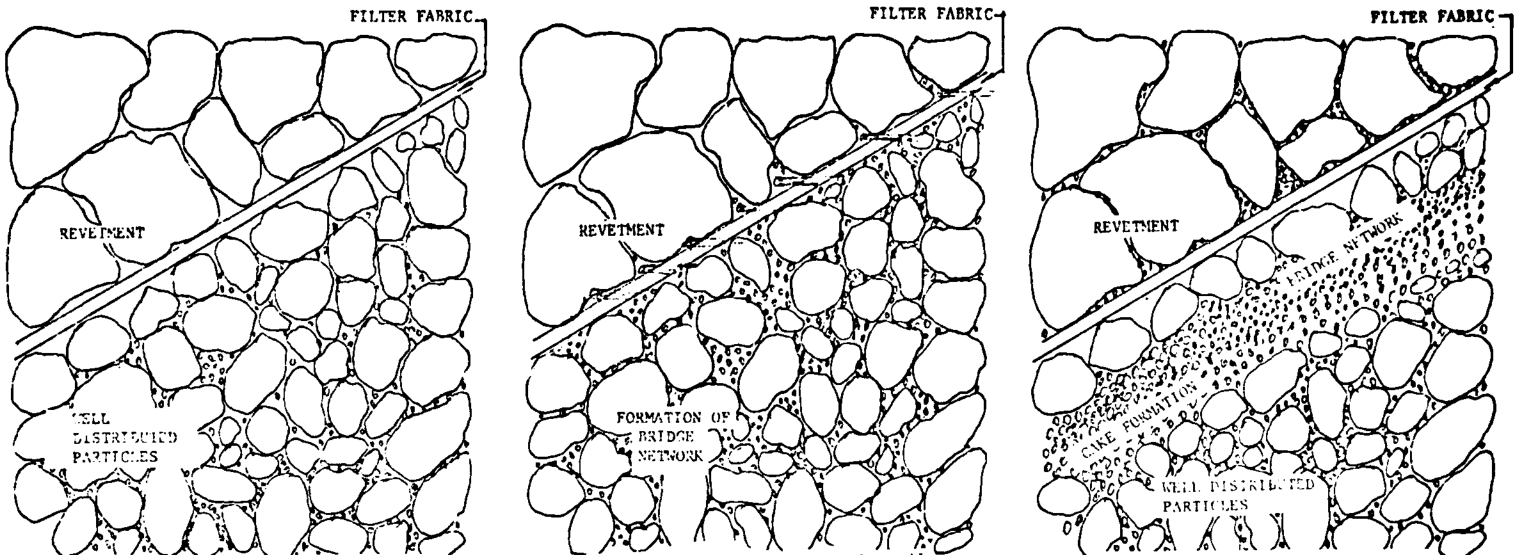


Figure 9. Filter fabric used as dike foundation support at site with unstable bearing conditions (the theoretical aspects of this problem are discussed by Haliburton et al. (1978))



a. Immediately after revetment construction, the soil particles of the streambank are well distributed.

b. As filtration begins, the soil particles are reoriented. A "bridging network" begins to form, and some of the fine particles pipe through the fabric.

c. In the mature fabric-soil filtration system, the bridging network is completed. A filter cake has formed, and the piping of fine particles through the fabric is virtually eliminated.

Figure 10. Sequence of formation of ideal fabric-soil filtration system (adapted from Marks (1975))

Figure 11. In-place sack revetment. The sacks were fabricated from filter fabric material

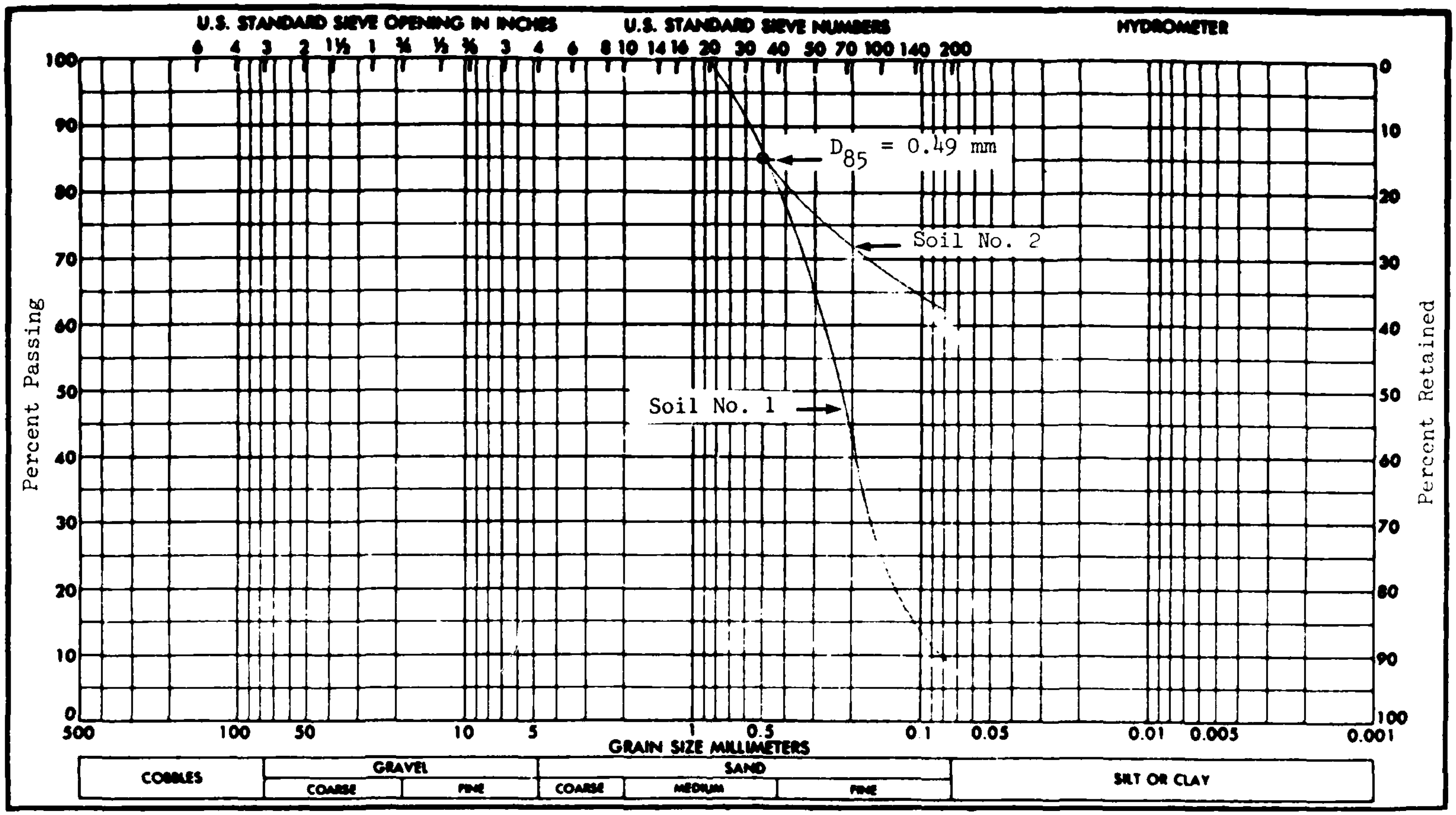


Figure 12. Gradations of soils used to illustrate filter criteria

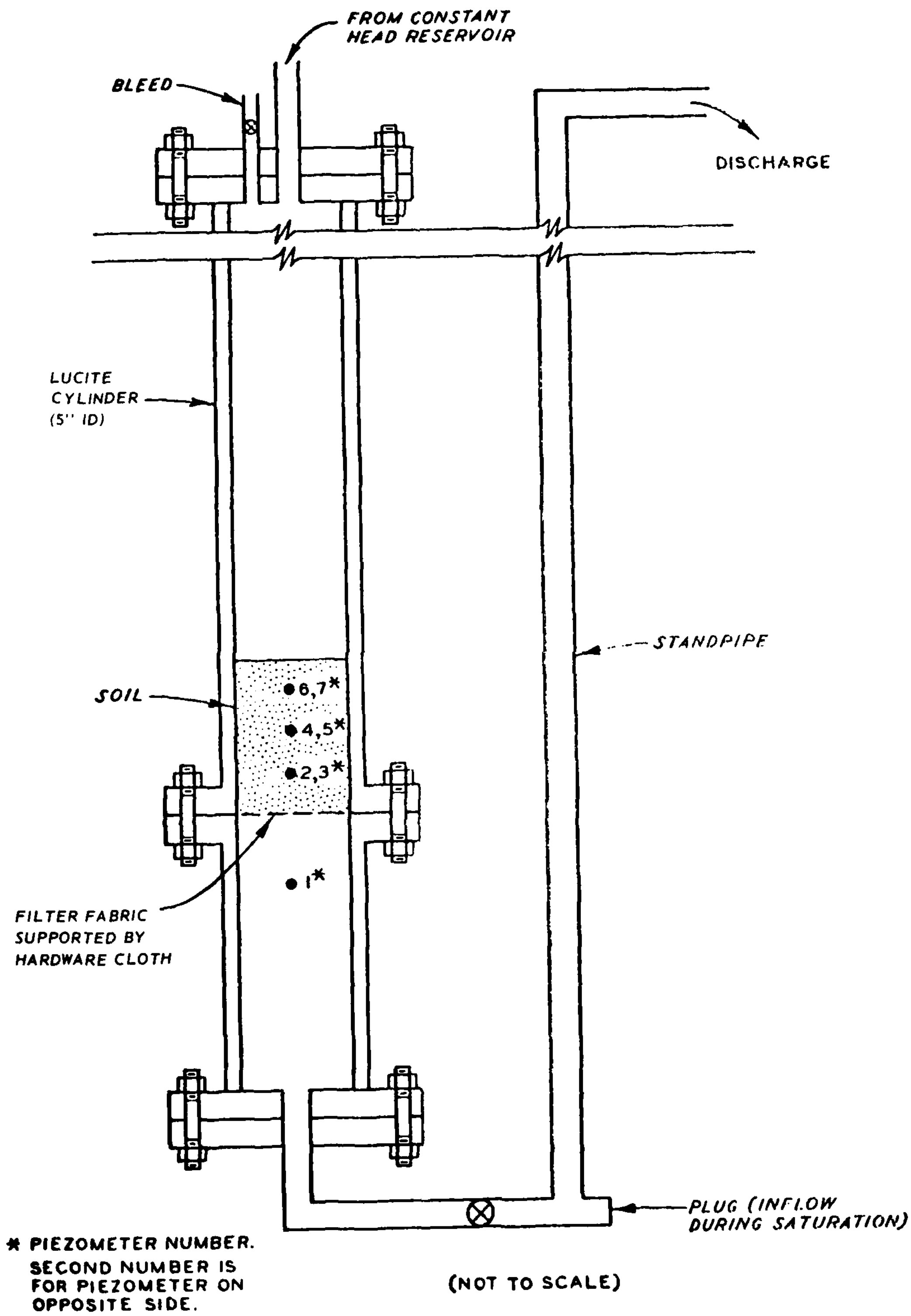


Figure 13. Apparatus used to perform the Gradient Ratio Test

Figure 14. Tearing of filter fabric at securing pin (ball-point pen for scale)

Figure 15. Loosely placed filter fabric of the Divide Cut Section of the Tennessee-Tombigbee Waterway

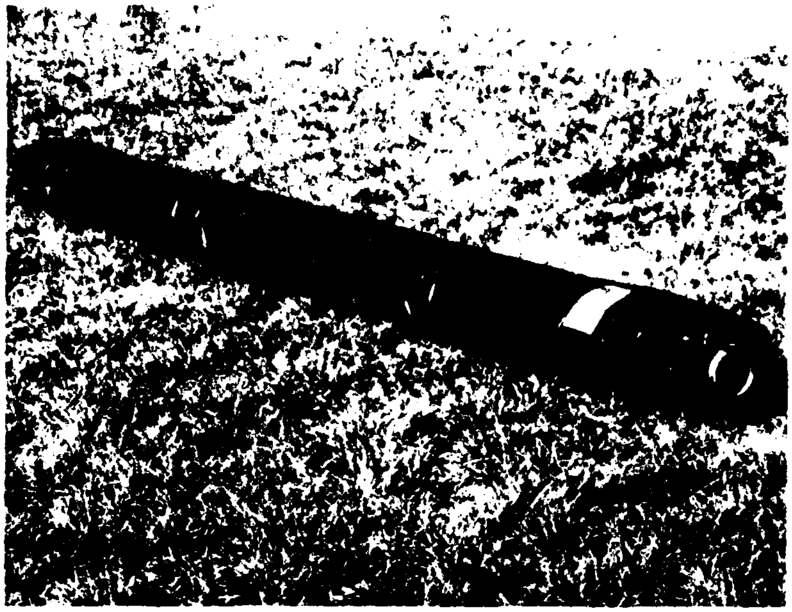


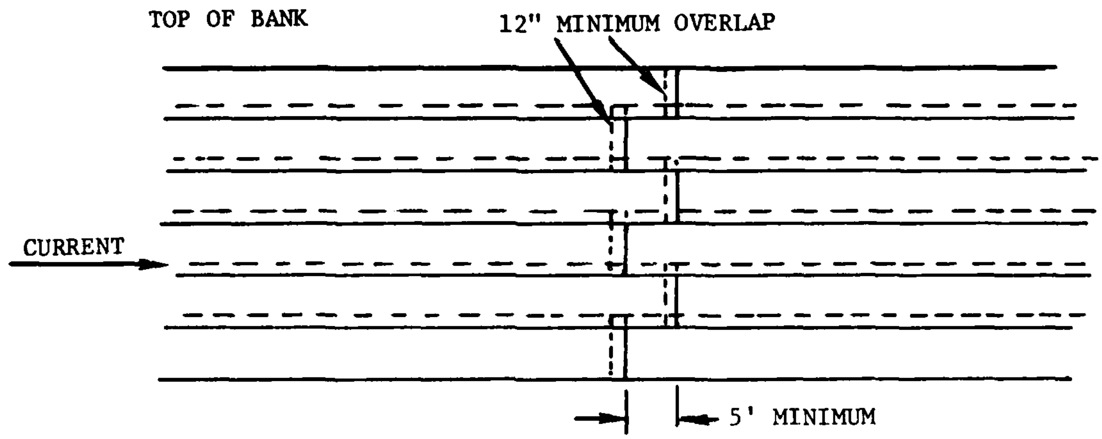
Figure 16. Filter fabric roll with protective covering (photograph courtesy of Celanese Fibers Marketing Co.)

Figure 17. Filter fabric sections being sewn together onsite

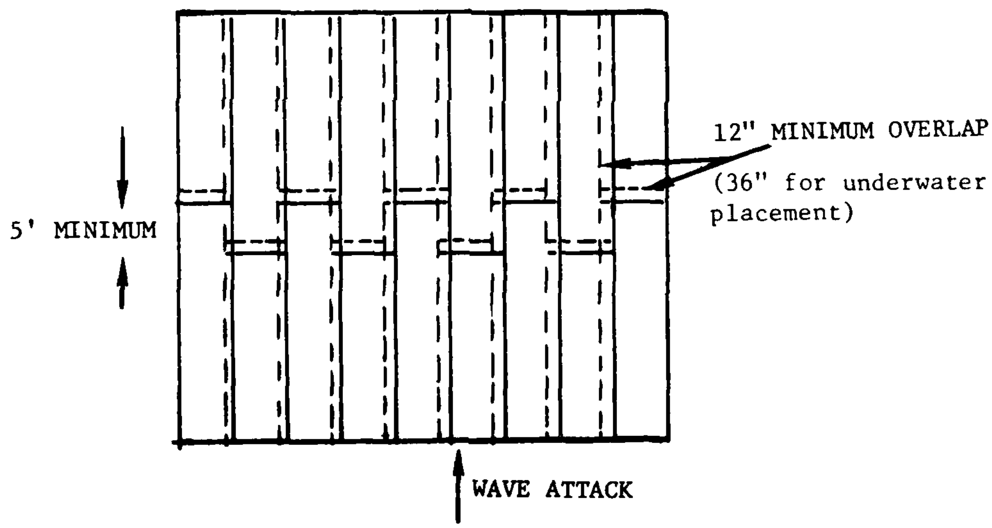
Figure 18. Inspection of completed seam

Figure 19. Filter fabric being pinned in place (photograph courtesy of Carthage Mills)

Figure 20. Filter fabric being spread on prepared bank (photograph courtesy of E. I. Dupont de Nemours and Co., Inc.)



a. Orientation for current acting parallel to bank



b. Orientation for wave attack normal to bank

Figure 21. Correct fabric placement for current acting parallel to bank or for wave attack on the bank

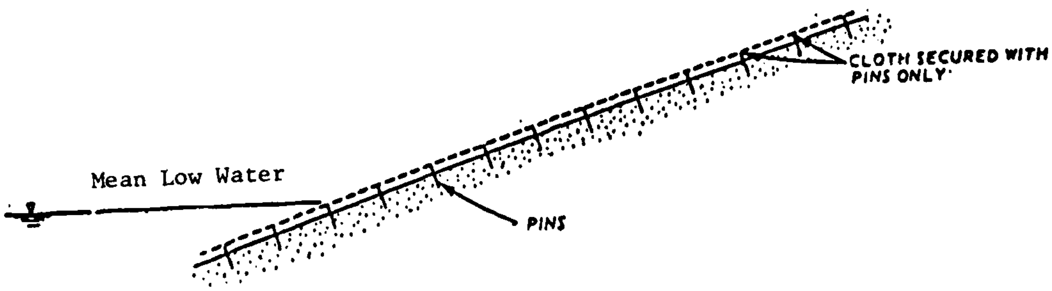


Figure 22. Placement of filter fabric on bank subject to streamflow action. Revetment materials have not yet been placed on the fabric

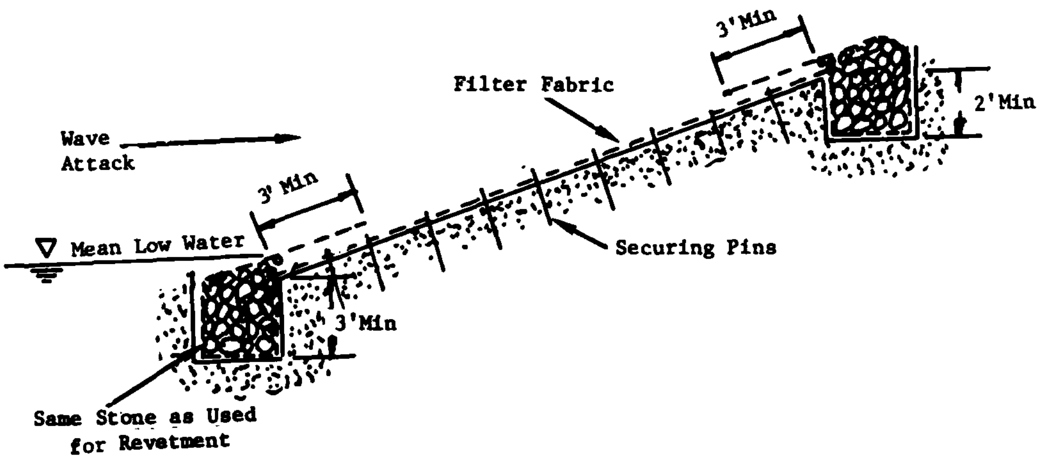


Figure 23. Filter fabric on bank subject to wave attack showing placement of vertical-wall key trench at toe and top bank. Revetment materials have not yet been placed on fabric

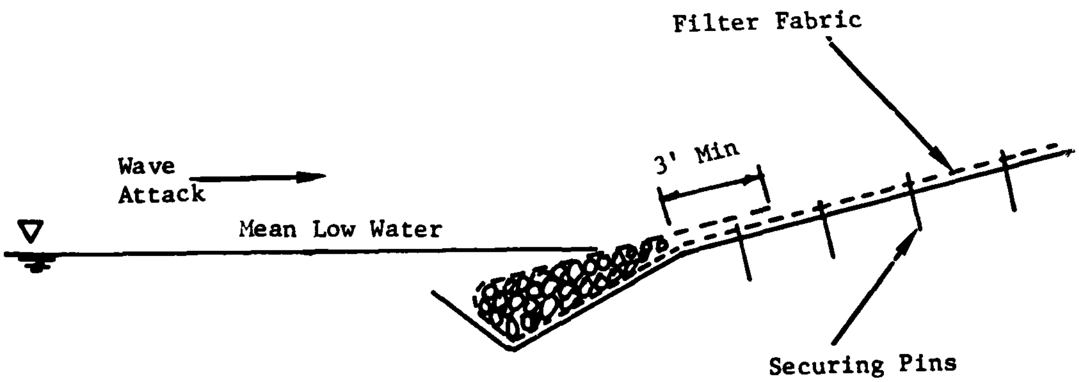


Figure 24. Key trench design used when soil conditions do not permit construction of vertical walls

Figure 25. Stone riprap being placed over primary layer of fine sandy gravel; note filter fabric under gravel (photograph courtesy of Celanese Fibers Marketing Co.)

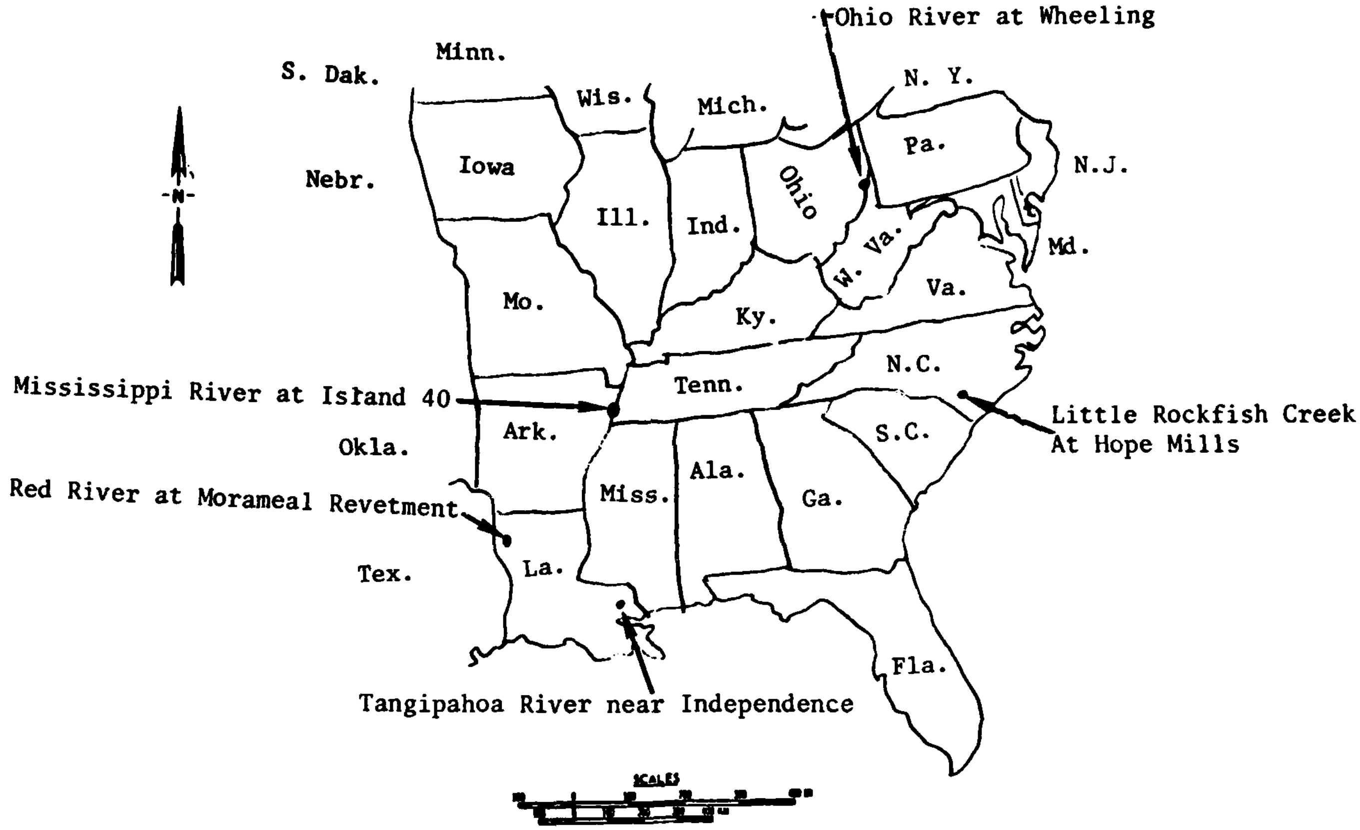


Figure 26. Locations of sites selected for case histories

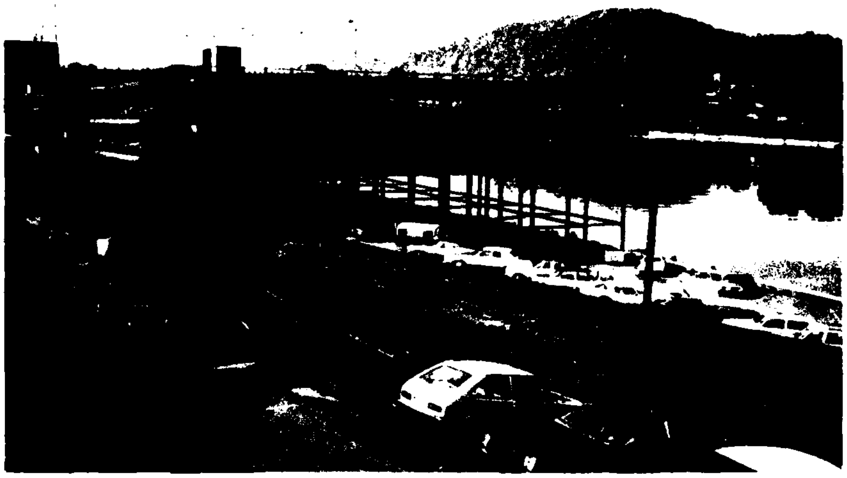


Figure 27. Wharf Parking Garage, Wheeling, W. Va.
(22 June 1978)

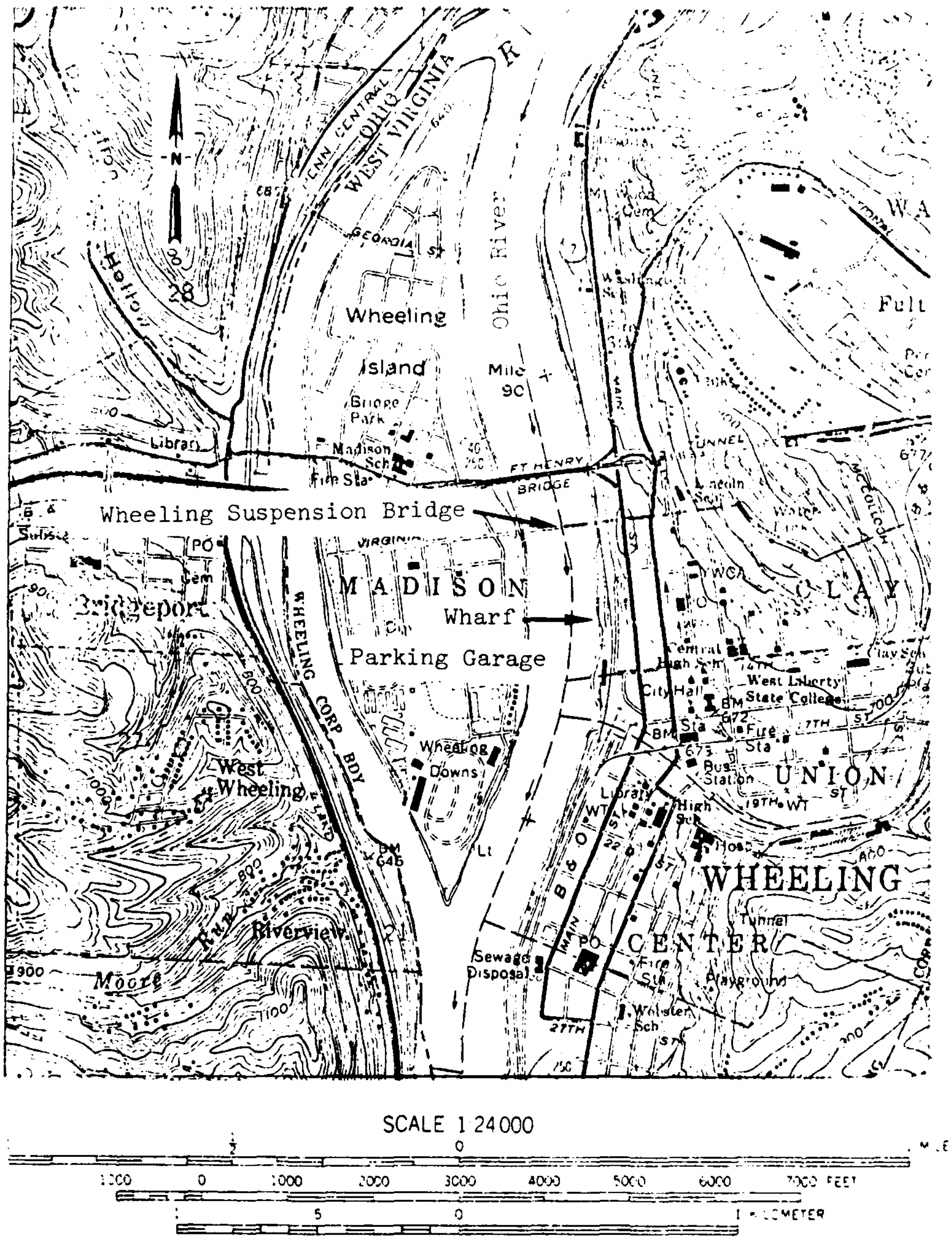


Figure 28. Location of revetment at Wheeling Wharf Parking Garage, Wheeling, W. Va. (Source: USGS 1:24,000 topographic quadrangle for Wheeling, W. Va.-Ohio, 1968 (Photo-revised 1978))

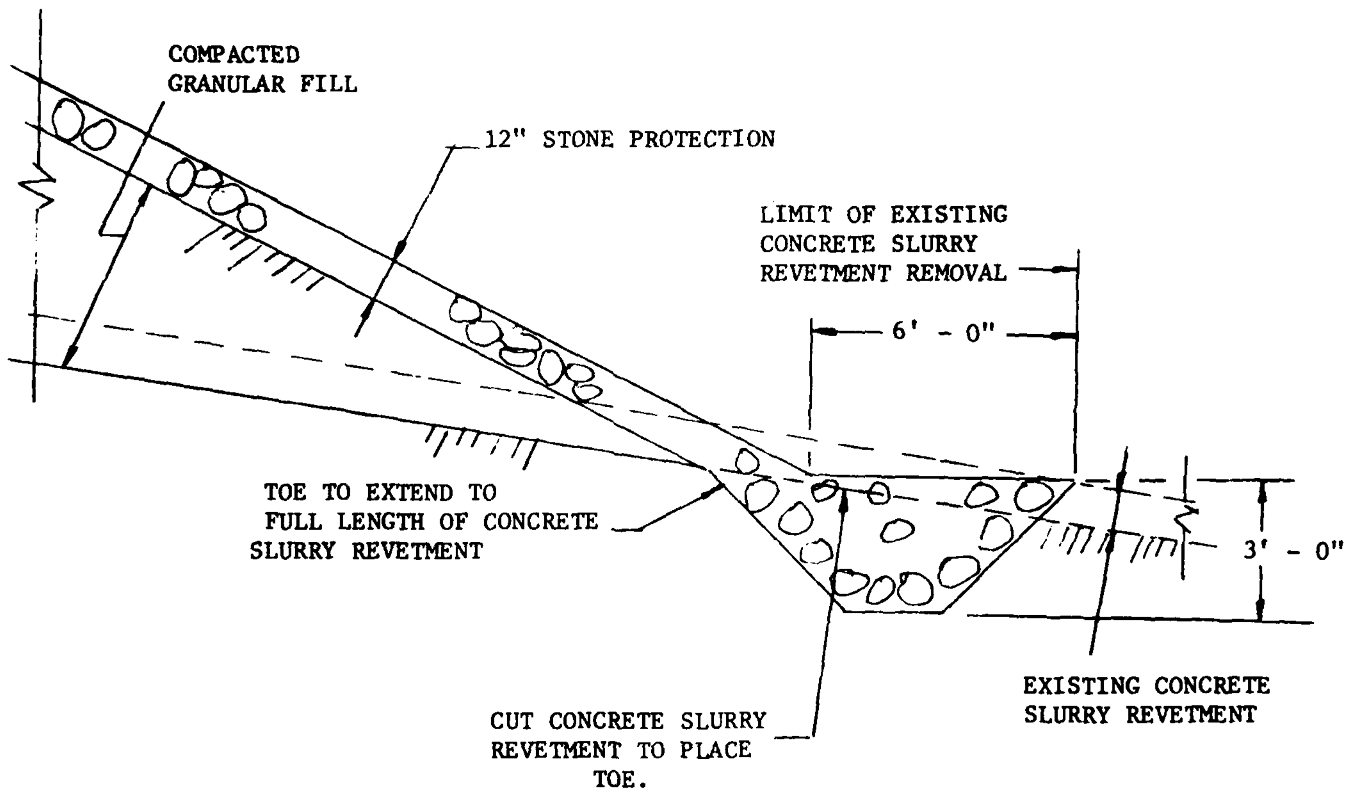


Figure 29. Typical cross section of the 1971 stone protection at the Wheeling Wharf Parking Garage (adapted from Ohio River, Hannibal Locks and Dam, Ohio and West Virginia, City of Wheeling, West Virginia - Alterations, Wharf Parking Garage, Drawing O-LHA-69/41, ORF, 12 May 1971)

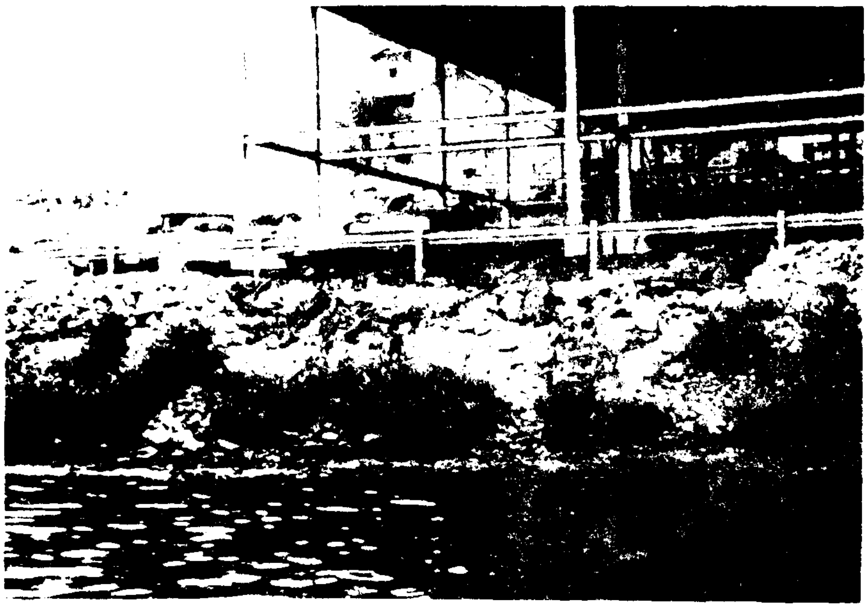


Figure 30. Damage to bank protection at Wheeling Wharf Parking Garage after the 1972 failure. Riprap has slid down the slope into the river and the filter fabric has ripped

Figure 31. Condition of revetment of Wheeling Wharf Parking Garage on 31 March 1972 showing how riprap and filter fabric were placed directly over exiting concrete slurry revetment without entrenching toe

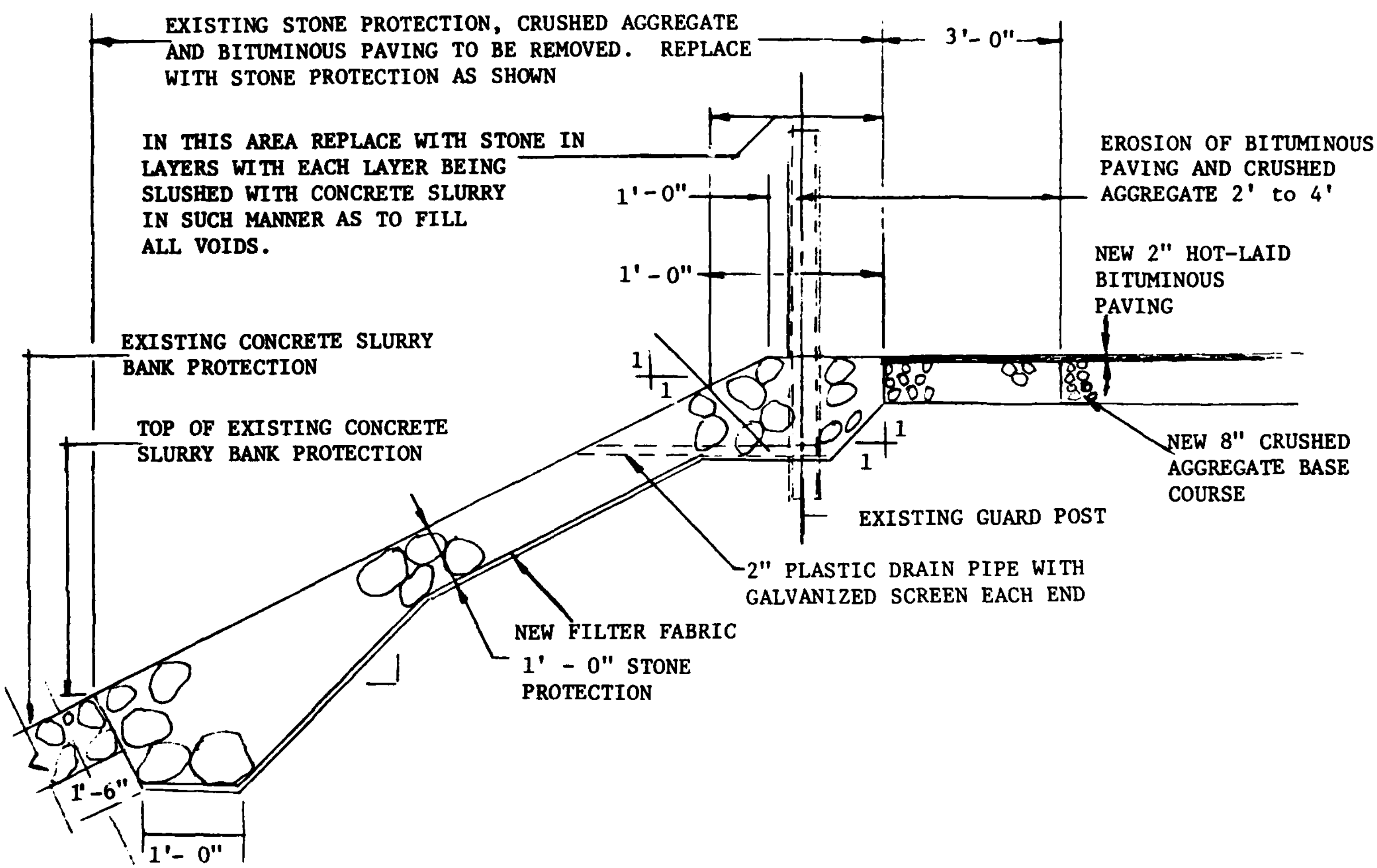
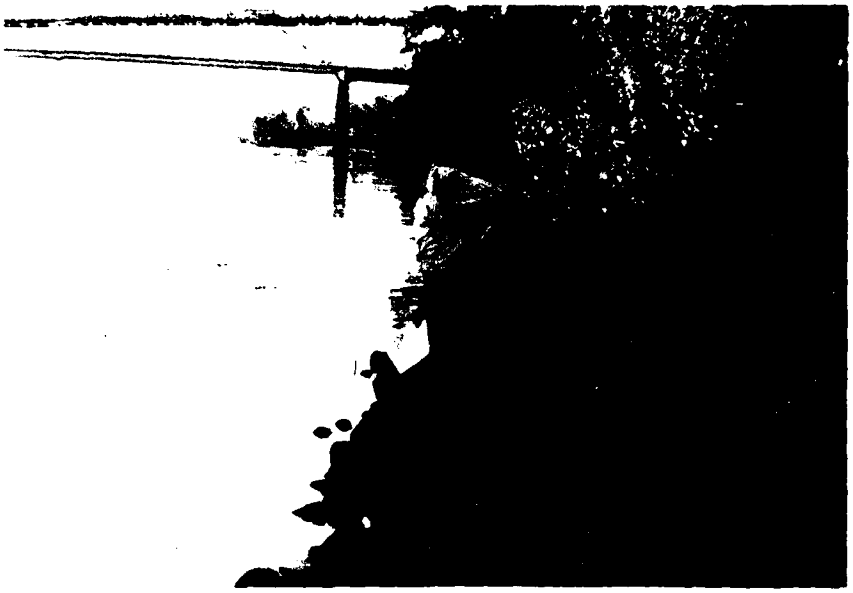


Figure 32. Profile view of 1973 repair to revetment, Wheeling Wharf Parking Garage (adapted from Ohio River Hannibal Locks and Dam, Ohio and West Virginia, Wharf Parking Garage, Slope Repair Drawing No. O-LHA-100167.1, ORP, not dated)

Figure 33. Exposed but undamaged filter fabric detected by WES Section 32 Program evaluation team at the Wheeling Wharf Parking Garage site (22 June 1978)

Figure 34. Failure of bituminous pavement near steel guard rail at Wheeling Wharf Parking Garage (22 Jun 1978)



[illegible] Some of the riprap used to repair the [illegible] failure of the revetment of the Wheeling Wharf Parking Garage slid over the original concrete slurry [illegible] and into the river ([illegible] Jun [illegible])

Figure 36. Condition of revetment at Wheeling Wharf Parking Garage on 19 Mar 1979. High flows during March 1979 pulled the filter fabric away from the bank and caused more riprap to slide into the river

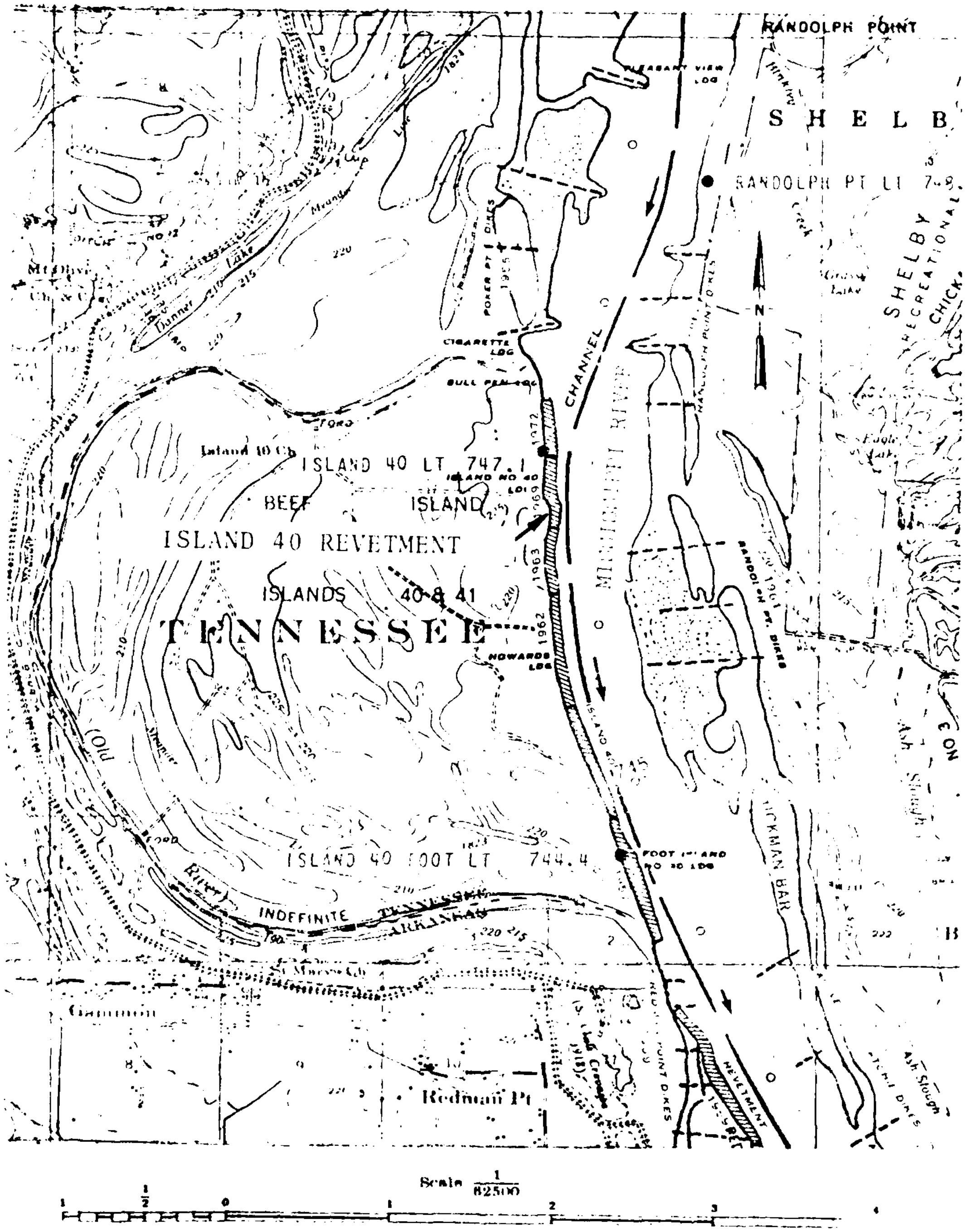


Figure 37. Location of articulated concrete mattress revetment at Island 40 near Memphis, Tenn. (Source: MRC 1976, Map No. 13)

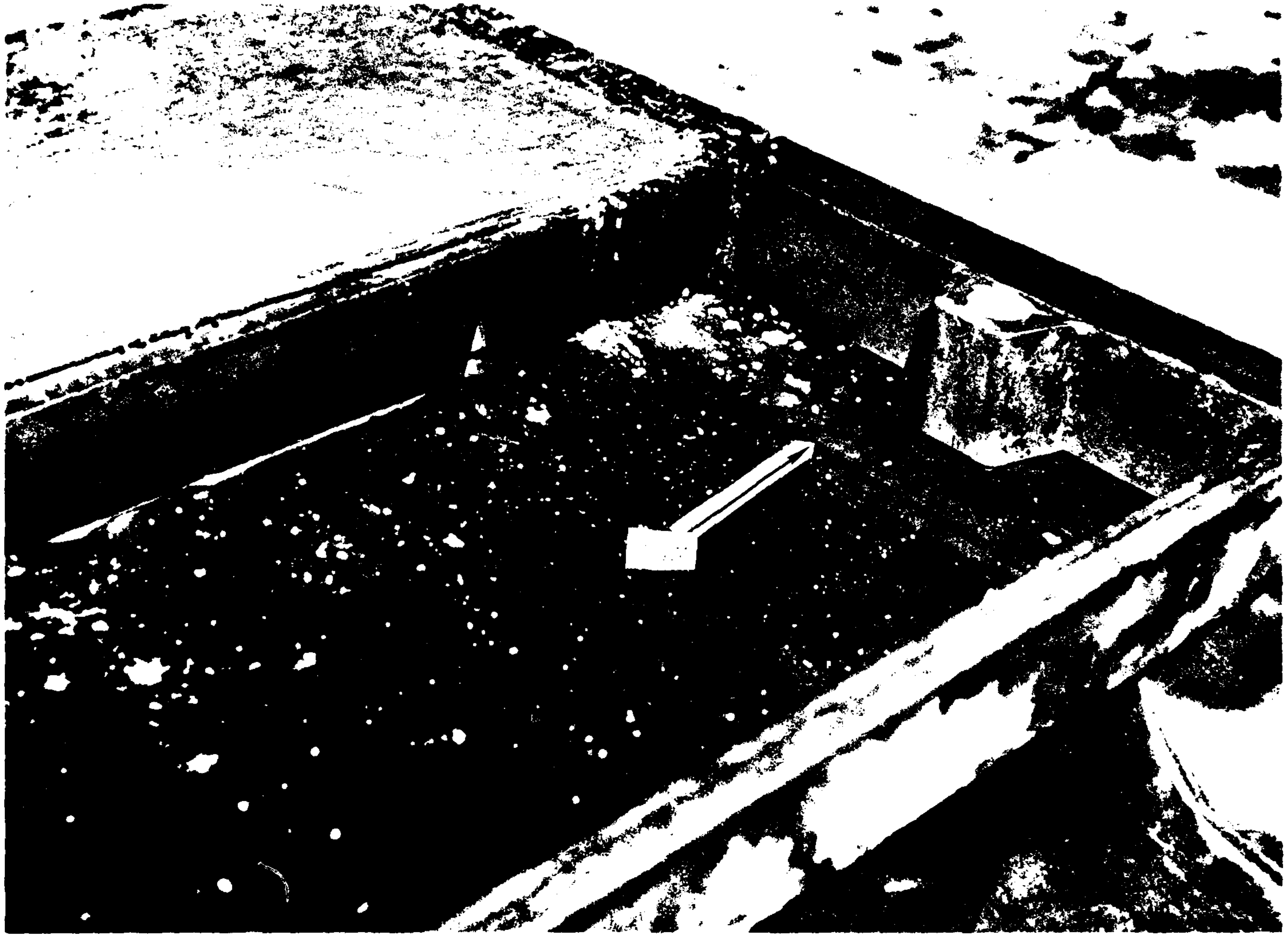


Figure [illegible] placed on filter fabric in laboratory tests to evaluate [illegible] qualities of [illegible]

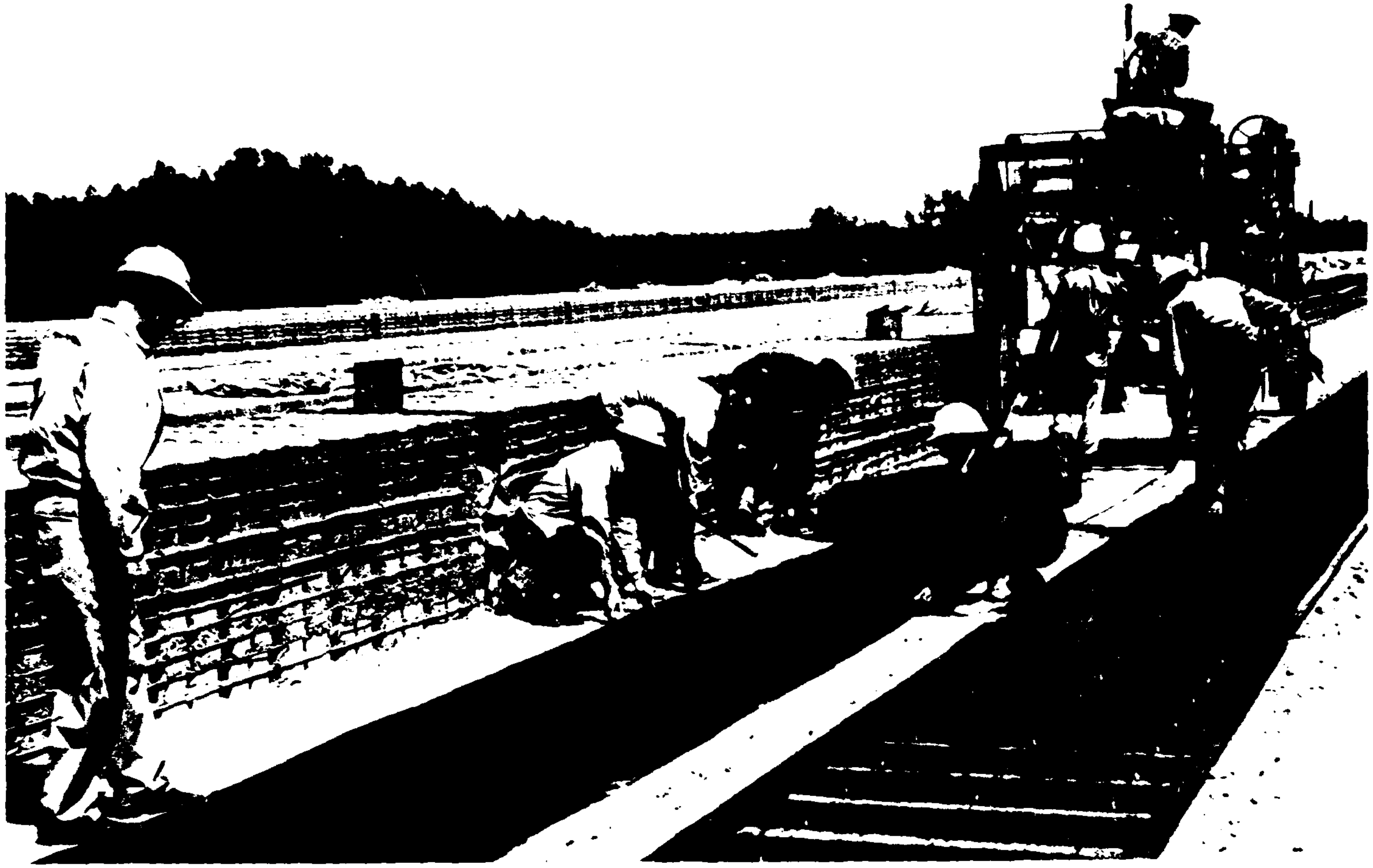


Figure 39. Filter fabric being unrolled on top of the kraft paper in preparation for casting the first layer of mattress in the stack

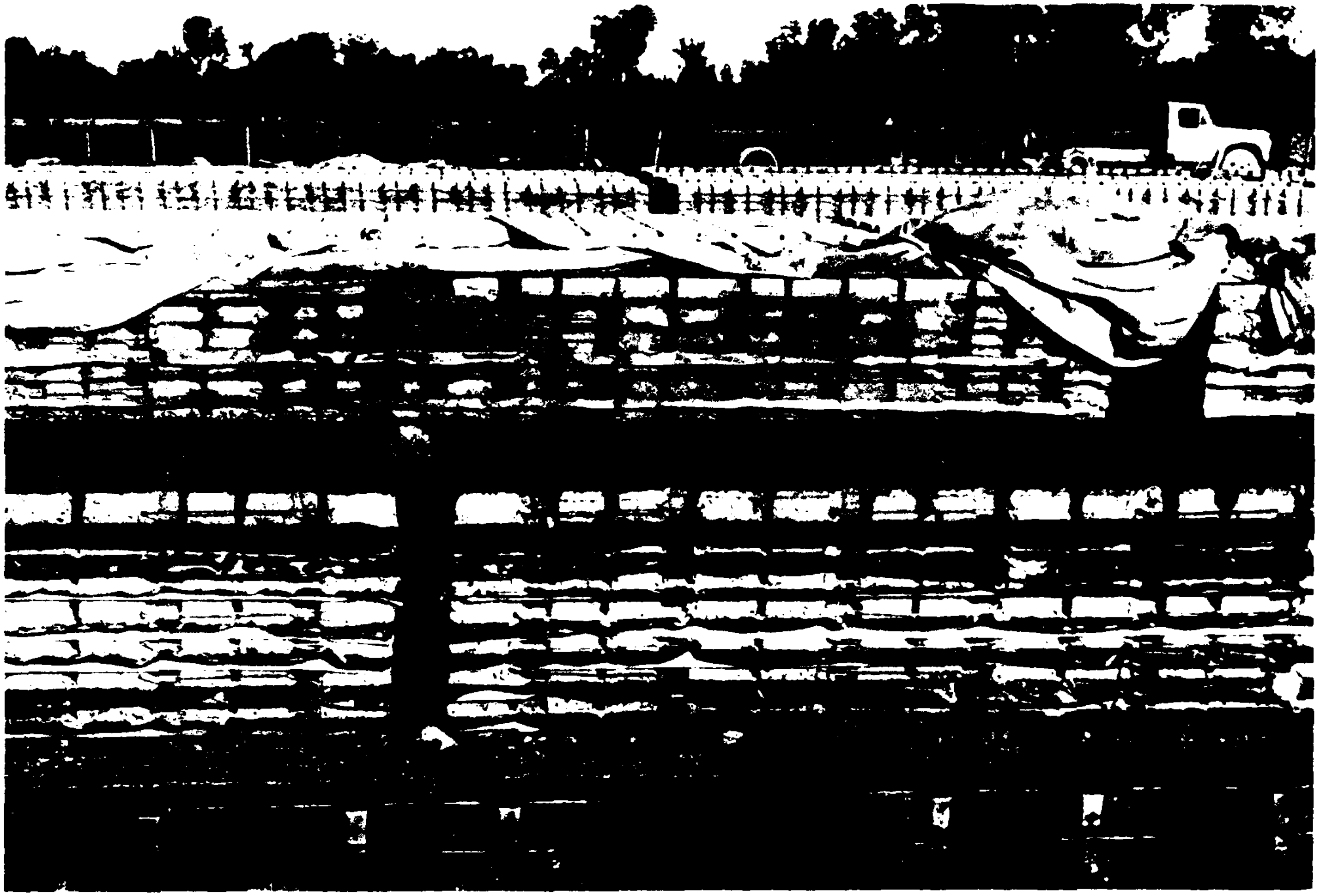


Figure 40. Stacks of mattress with filter fabric. The connecting length of fabric between the ends of the squares has been trimmed.

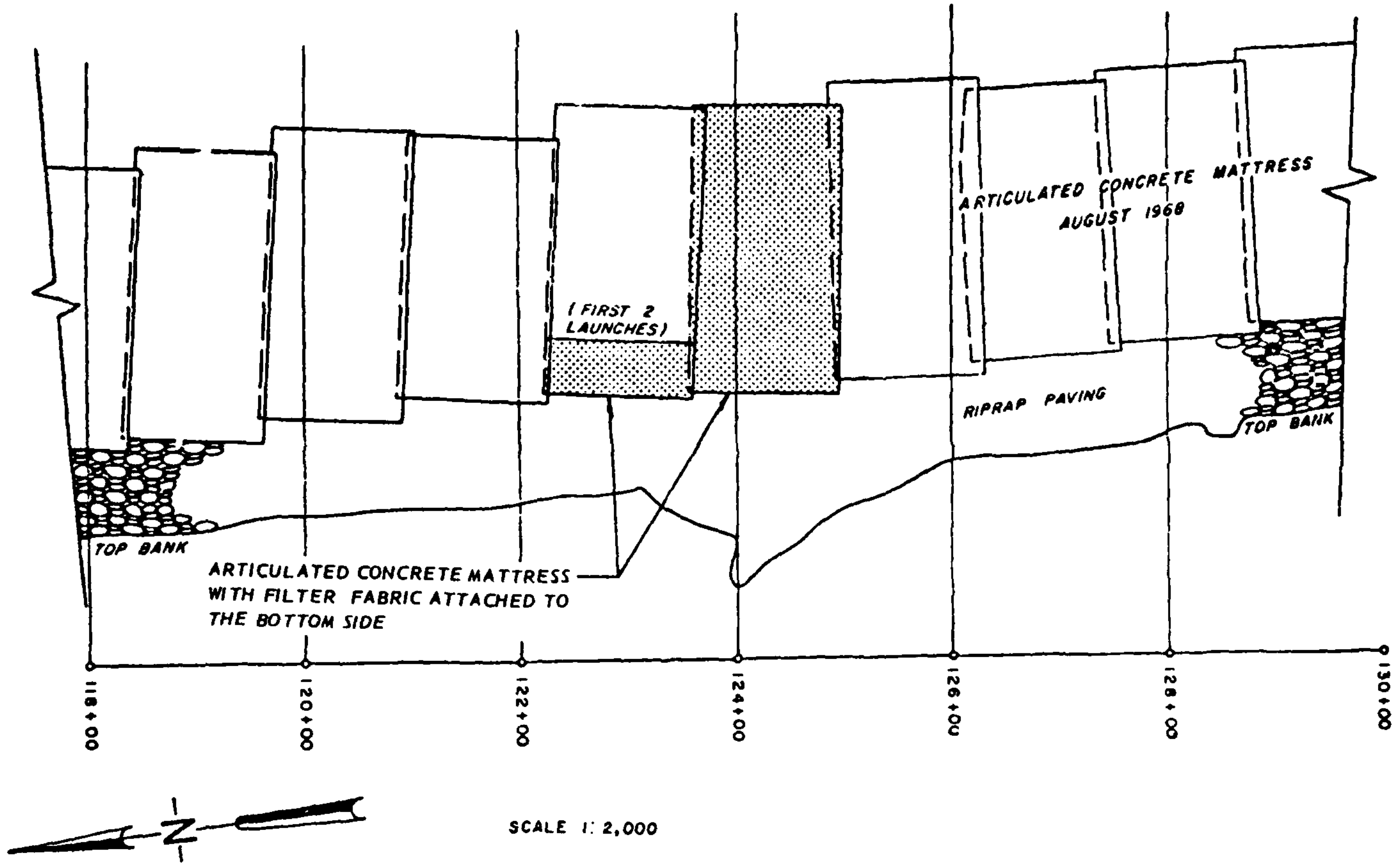


Figure 41. Plan view showing articulated concrete mattress revetment placed at Island 40 on the Mississippi River near Memphis, Tenn.

Figure 42. Automatic tying tool being used to make ties between mattress squares

Figure 43. A full mattress consisting of the experimental squares bonded to the filter fabric being launched

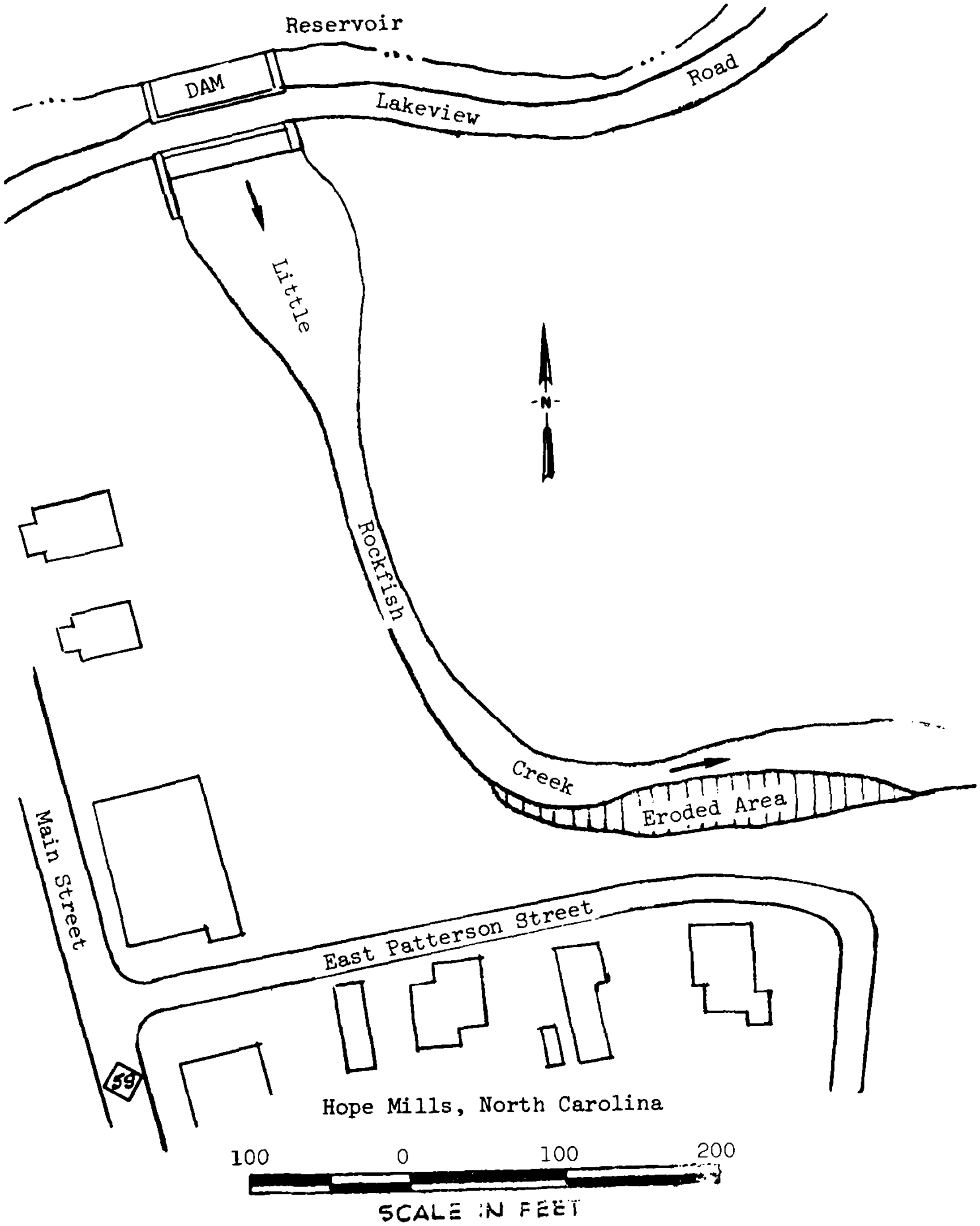


Figure 44. Location of eroded area on right bank of Little Rockfish Creek at Hope Mills, N. C. (adapted from Little Rockfish Creek, Hope Mills, N. C., General Map and Site Plan, Drawing No. RC 102-02-28, Sheel 1 of 2, SAW, 19 Sep 1975)

Figure 46. Upstream view of erosion on Little Rockfish Creek, Hope Mills, N. C., as it appeared in April 1973

Figure 47. Downstream view of erosion on Little Rockfish Creek, Hope Mills, N. C., as it appeared in April 1973

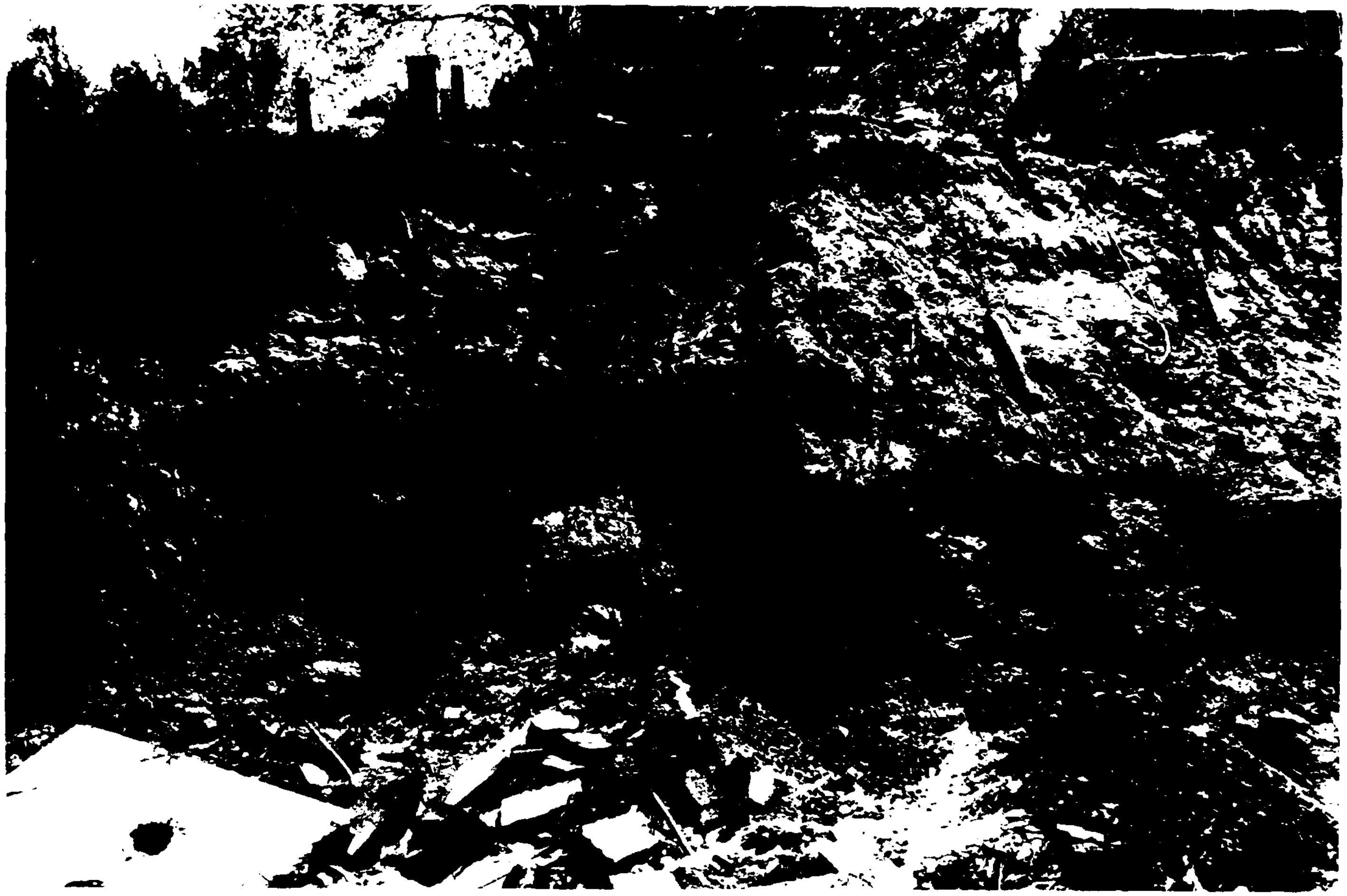


Figure 48. Broken concrete rubble dumped by the Town of Hope Mills, N. C., on the bank of Little Rockfish Creek in attempt to control erosion (April 1973)

Figure 49. Gabions being placed on filter fabric during construction of revetment on Little Rockfish Creek, Hope Mills, N. C., 1976

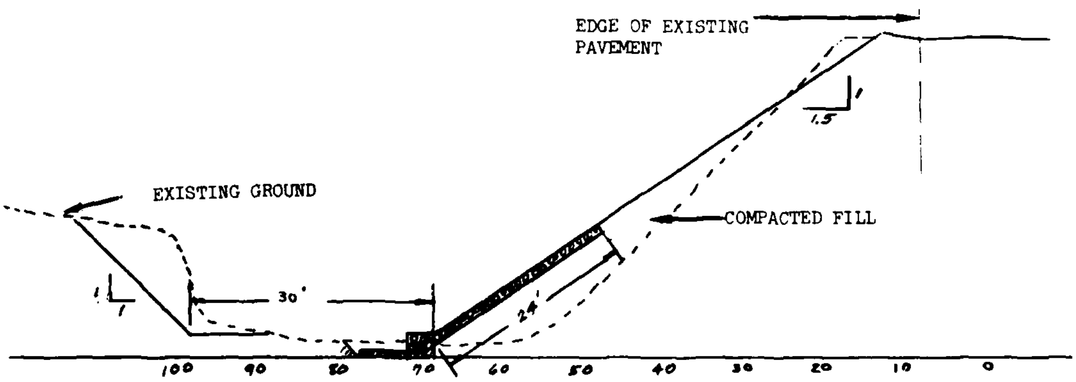


Figure 50. Typical cross section of revetment placed on Little Rockfish Creek, Hope Mills, N. C. (adapted from Little Rockfish Creek, Hope Mills, N. C., Slope Protection, Cross Sections, Drawing No. RC 102-02-28, Sheet 2 of 2, SAW, 19 Sep 1975)

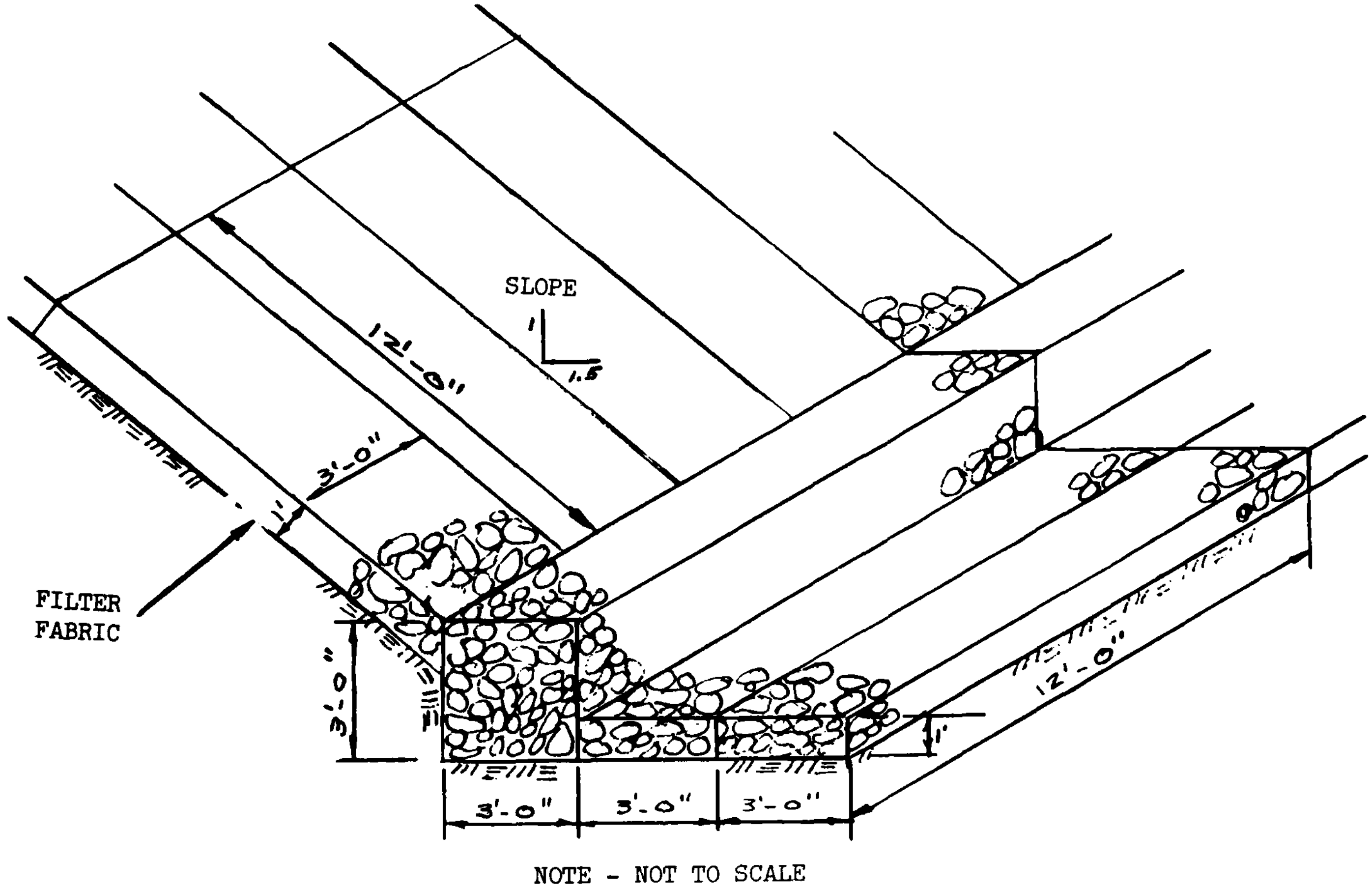


Figure 51. Typical gabion placement (adapted from Little Rockfish Creek, Hope Mills, N. C., Slope Protection, Cross Sections, Drawing No. RC 102-02-28, Sheet 2 of 2, SAW, 19 Sep 1975)

AD-A090 821 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
UTILIZATION OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICAT--ETC(U)
JUL 80 M P KEOWN, E A DARDEAU
UNCLASSIFIED WES/TR/HL-80-12 NL

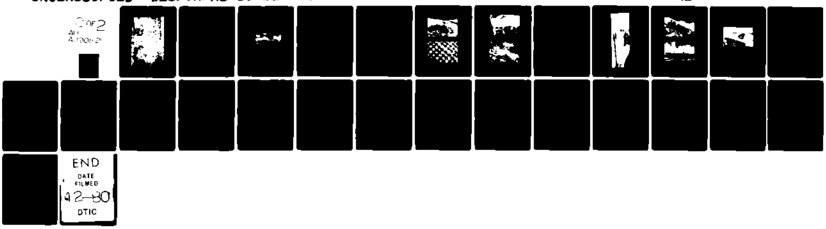


Figure 53. Downstream end of repaired gabion installation at Little Rockfish Creek, Hope Mills, N. C., as it appeared in November 1977

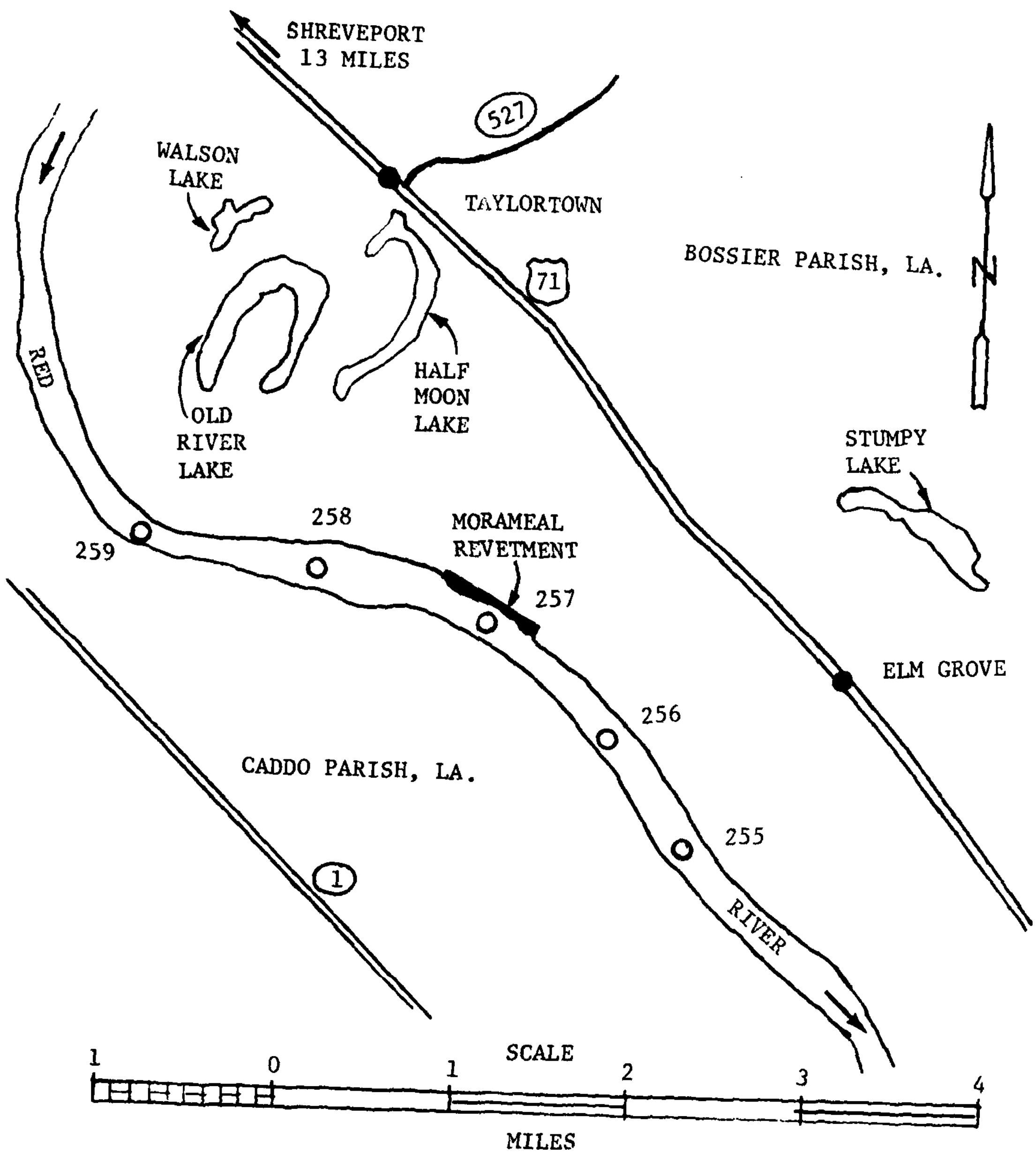


Figure 54. Location of Morameal Revetment, La.

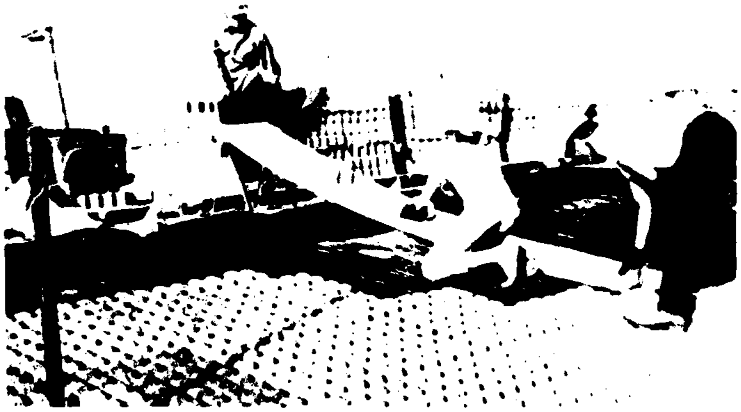


Figure 55. Typical hand-placement procedure used for assembly of precast cellular block section of Morameal Revetment, La. (1975) (photograph courtesy of ERCO Systems, Inc.)

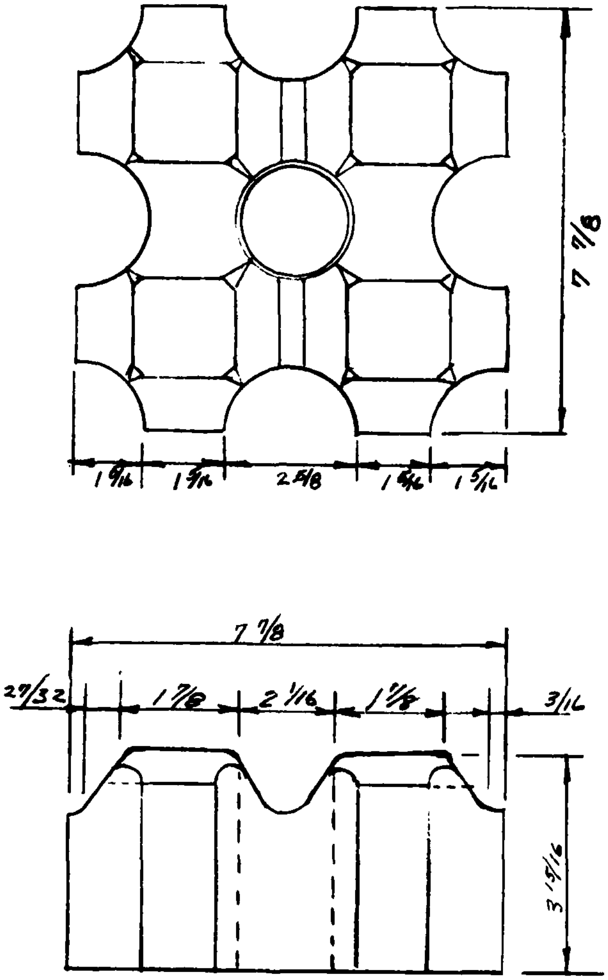


Figure 56. Dimensions of cellular concrete blocks used in construction of Morameal Revetment (Source: "Red River, Morameal, Bossier Parish, Lousiana, Experimental Revetment Item R-257.0-L (1967 Mileage), Sections and Profile", File No. K-108-26744, Drawing 6 of 8, LMN, April 1974)

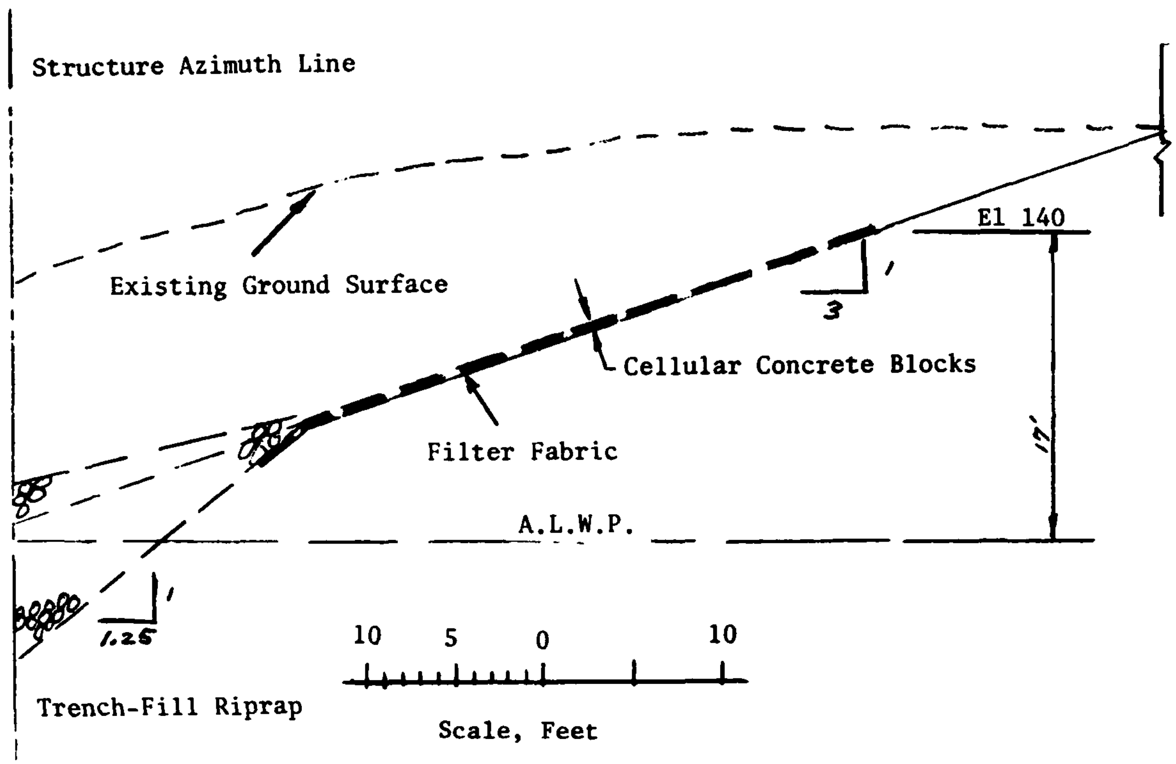


Figure 57. Typical cross section showing placement of precast cellular blocks at Morameal Revetment. Adapted from "Red River, Morameal, Bossier Parish, Louisiana, Experimental Revetment Item R-257.0-L (1967 Mileage), Sections and Profile," File No. K-108-26744, Drawing 6 of 8, LMN, April 1974

Figure 58. General downstream view of cellular block section of Morameal Revetment, La. (9 May 1978)

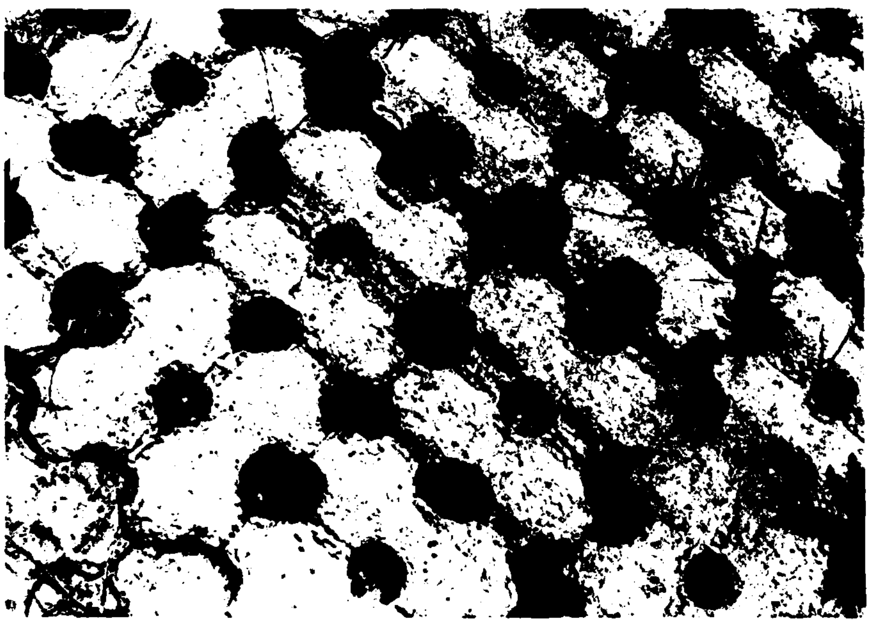


Figure 59. Filter fabric visible through precast cellular blocks Morameal Revetment, La. (9 May 1978)

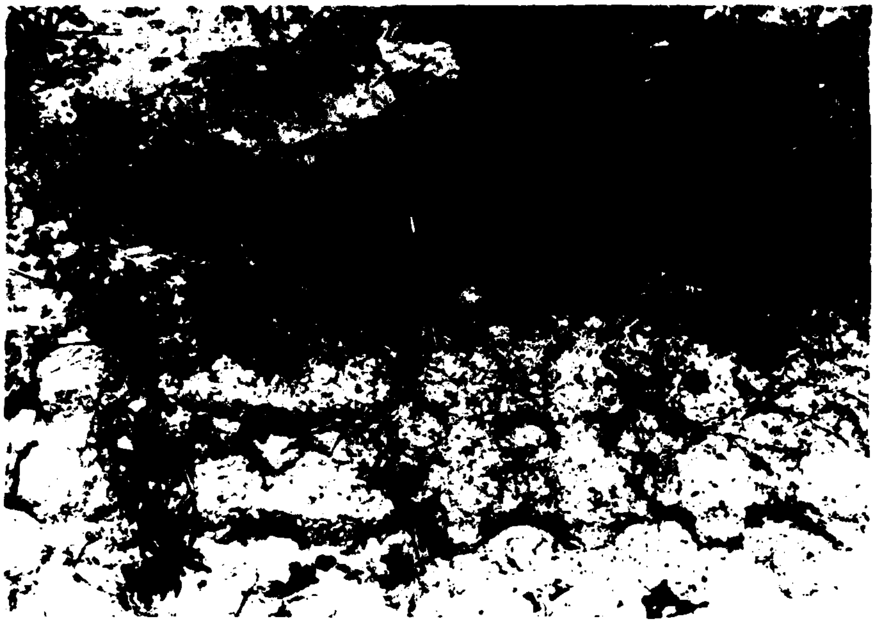


Figure 60. Filter fabric exposed at the landward edge of precast cellular block section, Morameal Revetment, La. (9 May 1978)

Figure 61. Piping detected beneath the filter fabric, Morameal Revetment, La. (9 May 1978)

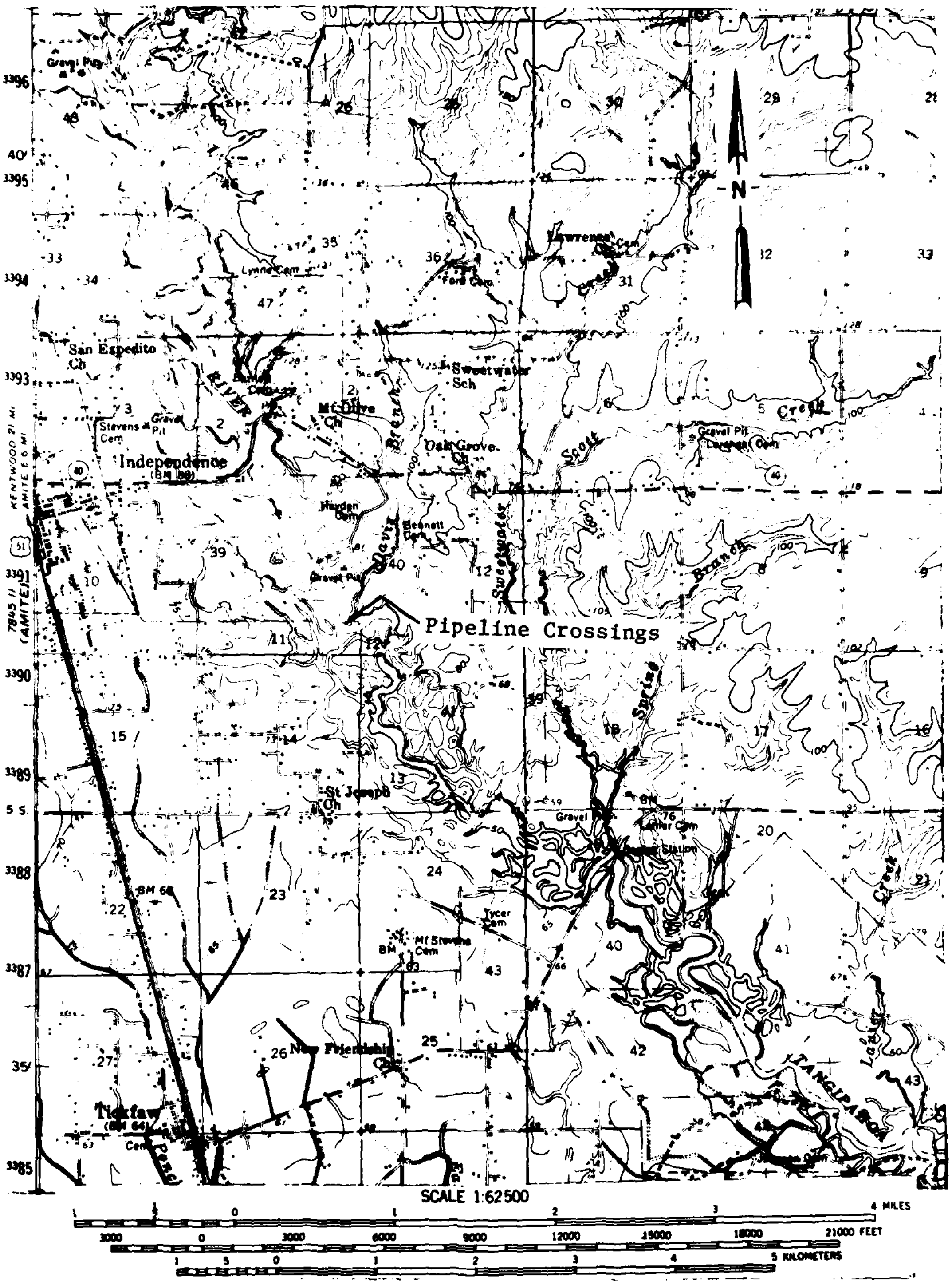


Figure 62. Location of Southern Natural Gas Company's Pipeline Crossings on the Tangipahoa River near Independence, La. (Source: USGS 1:62,500 topographic quadrangle map for Hammond, La., 1959)

Figure 63. Panoramic upstream view of Henson Permeable Spur Jetties installed by Hold-That-River, Inc., on the Tangipahoa River near Independence, La., (8 Apr 1974) (photograph courtesy of Southern Natural Gas Company)

Figure 64. Jetty system on Tangipahoa River near Independence, La., after failure caused by flooding (1977) (photograph courtesy of ERCO Systems, Inc.)

Figure 65. Gobimats being placed on left bank of Tangipahoa River upstream from pipeline crossing near Independence, La. (April 1978) (photograph courtesy of ERCO Systems, Inc.)

Figure 66. Completed Gobimat installation on Tangipahoa River upstream from pipeline crossing near Independence, La. (May 1978) (photograph courtesy of ERCO Systems, Inc.)

APPENDIX A: LISTING OF COMMERCIAL CONCERNS THAT MARKET FILTER FABRIC PRODUCTS

1. A listing of commercial organizations that market filter fabric products is provided below.

Company	Address	Product Trade Name(s)
Advance Construction Specialties Co.	P. O. Box 17212 Memphis, Tenn. 38117	Laurel Erosion Control Cloth
American Enka Co.	Enka, N. C. 28728	Enkamat Stabilenka
AMOCO Fabrics Co.	550 Interstate North Atlanta, Ga. 30339	ProPex
Bay Mills Midland, Limited	Midland, Ontario, Canada L4R 4G1	Bay Mills
Bradley Materials	P. O. Box 254 Valparaiso, Fla. 32580	Filter Weave Filter Weave Self-Sealing Erosion Control Bags Polyfelt* TS-200 TS-300, TS-400
Carthage Mills	124 W. 66th St. Cincinnati, Ohio 45216	Filter-X Poly-Filter X Poly-Filter GB
Celanese Fibers Marketing Co.	P. O. Box 1414 Charlotte, N. C. 28232	Mirafi
Crown Zellerbach Corp.	P. O. Box 877 Camas, Wash. 98607	Fibertex
E. I. DuPont de Nemours and Co., Inc.	1007 Market St. Wilmington, Del. 19898	Typar
Kenross-Naue, Inc.	131 Golf Terrace Daphne, Ala. 36526	Terrafix Lotrak
Koch Brothers, Inc.	35 Osage Ave. Kansas City, Kans. 66105	Zenith
Monsanto Textiles Co.	800 N. Lindbergh Blvd. St. Louis, Mo. 63166	Bidim

* Polyfelt line manufactured by Chemie-Linz of Linz, Austria.

Company	Address	Product Trade Name(s)
Nicolon Corp.	4229 Jeffrey Drive Baton Rouge, La. 70815	Nicolon X, 70, 70L, 40, 40L, LD 1000, MD 7500, HD 10000, HD 20000, HD 40000, HD 7500
Phillips Fibers Corp.	P. O. Box 66 Greenville, S. C. 29602	Supac
Staff Industries, Inc.	P. O. Box 797 Upper Montclair, N. J. 07043	Permealiner
J. P. Stevens and Co., Inc.	Stevens Tower 1185 Avenue of the Americas New York, N. Y. 10036	Monofilter
Tex-el, Inc.	485, Des Erables St.-Elzear, Beauce Nord Quebec GOS 2J0 Canada	Tex-el

APPENDIX B: GLOSSARY OF TERMS RELATED TO THE LABORATORY TESTING AND PLACEMENT OF FILTER FABRIC FOR STREAMBANK PROTECTION APPLICATIONS

Abrasion resistance of fabric. The test of cloth-wearing properties performed in accordance with ASTM D-1175-71, "Tests for Abrasion Resistance of Textile Fabrics." The abrasive wheels are the rubber base type equal to the CS-17, "Calibrase," manufactured by Taber Instrument Company. The load on each wheel is 1000 g, and the test is continued for 1000 revolutions. One-in.-wide jaws are used, and the constant rate of traverse is 12 in./min.

Articulated concrete mattress. Rigid concrete slabs usually hinged together with corrosion-resistant wire fasteners; designed primarily for subaqueous protection.

Bank protection. (1) Armor placed on a streambank to stabilize it against stream attack; (2) a river training structure, designed to deflect erosive hydraulic flows away from a streambank.

Brittleness of fabric. Evaluation of the strength of filter fabric at low temperatures, performed in accordance with CRD-C 570-64, "Brittleness, Low Temperature, Motor Driven Apparatus."

Burst strength of fabric. Test used to determine the equivalent hydrostatic force required to fail a fabric in a specified test ring; performed in accordance with ASTM D-751-68, "Testing Coated Fabrics."

Calendering. Process of pressing fabric between rollers to give it a smooth surface, usually associated with application of heat to give a permanent set to the fabric.

Carrier fabric. Material to which precast cellular blocks are attached with adhesive; placed with a mobile crane as a unit on an eroding streambank.

Cut bank. The concave bank of a meandering stream that is maintained as a steep or even overhanging cliff by the impinging streamflow against its base.

Dike (sill, groin, spur, jetty). A river training structure constructed of earth, wood, or stone designed to deflect erosive currents away from a bank and to control movement of bed material.

Elongation of fabric. The ratio of the difference of the length of a fabric test specimen at failure to its original length divided by its length at failure, expressed as a percent, i.e. $((L_f - L_o)/L_f) \times 100$ where L_f is the length at failure and L_o the original length; test performed in accordance with ASTM D-1682-64, "Breaking Load and Elongation of Textile Fabrics."

Equivalent Opening Size (EOS) of fabric. The EOS is the number of the U. S. Standard sieve having openings closest in size to the filter fabric openings. The lower EOS numbers have larger fabric openings.

Filament. A single thread of material used to weave fabric.

Fill of the fabric. The direction of the filaments perpendicular to the long axis of the fabric.

Filter. Layer(s) of sand, rock, or fabric (or combinations thereof) placed between the bank armor and soil for one or more of three purposes: to prevent the soil from traveling through the armor, to prevent the armor from sinking into the soil, and to permit natural seepage from the streambank to occur and thus prevent buildup of excessive hydrostatic pressure.

Filter fabric. Material produced by a woven or nonwoven manufacturing process used for application as described under the definition of a filter.

Freeze-thaw. Evaluation of the short-term strength of filter fabric that is subjected to freeze-thaw cycles; performed in accordance with CRD-C 20-71, "Resistance of Concrete to Rapid Freezing and Thawing."

Gabions. Bank revetment consisting of compartmental rectangular or cylindrical baskets constructed from galvanized steel wire mesh, filled with earth, stone, or other types of locally available material.

Graded filter. A layered media designed to provide a gradual reduction in material size between the revetment and bank, such that the lower layered materials blend with the bank materials.

Gradient ratio (GR). The ratio of the hydraulic gradient over the 1 in. of soil immediately next to the filter fabric (i_f), to the hydraulic gradient over the 2 in. of soil between 1 and 3 in. above the fabric (i_g). This test is performed in a constant head permeameter with a 4-in. soil sample over the fabric under a total head of about 12 in.

Grab test of fabric (pounds). A test of fabric strength in which only a part of the width of the fabric specimen is gripped in clamps (typically 1-in. square jaws and a travel rate of 12 in./min); performed in accordance with ASTM D-1682-64, "Tests for Break Load and Elongation of Textile Fabrics."

Hydraulic gradient. The ratio of head loss to the length of the flow path.

Needle-punching. The process where barbed needles are punched through fabric to entangle the fibers.

Nonwoven fabric. Material manufactured from fibers spun in a continuous process to produce a random pattern, usually with no distinct visible openings in the fabric.

Oxidation of fabric. Test to determine influence of oxygen on filter fabric, i.e. the chemical reaction of the fabric with oxygen that alters the fabric strength. Tests are made in accordance with CRD-C 577-60, "Oxygen Pressure Test."

Plastic filter fabric. Material fabricated from filaments which are petrochemical in origin.

Precast cellular block. Regularly cavitated block, manufactured offsite and often placed on filter fabric as a substitute for stone riprap when quality stone is not readily available or when its cost is prohibitive.

Puncture strength of fabric. Resistance of fabric to piercing over a small area by an intense load; performed in accordance with ASTM 751-68, "Testing Coated Fabrics," except that polished steel ball is replaced by a 5/16-in.-diam solid steel cylinder.

Revetment. Armor of erosion-resistance material designed to protect a bank against stream attack.

Sack revetment. Armor consisting of sacks (e.g. burlap, paper, plastic, nylon, etc.) filled with concrete, sand, stones, or other available material and placed on a streambank to serve as protection against erosion.

Seam strength of fabric. A tensile test to determine the strength of a sewed fabric seam; performed in accordance with ASTM-1683-68, "Test for Seam Breaking Strength of Woven Textile Fabrics."

Securing pin. Elongated steel rod used to hold filter fabric in place on a streambank.

Stone riprap. Natural cobbles, boulders, or broken stones dumped or placed on a streambank or filter as armor against erosion.

Strip test of fabric. A test of fabric strength in which the full width of the specimen is gripped in the clamps (typically 1 in. or wider with the jaws at a travel rate of 12 in./min); performed in accordance with ASTM D-1682-64, "Tests for Break Load and Elongation of Textile Fabrics."

Tensile strength of fabric. Maximum tensile stress that can be sustained by fabric; may be performed in accordance with ASTM D-1682-64, "Tests for Break Load and Elongation of Textile Fabrics."

Thickness of fabric (mils). Loose thickness of a fabric in 1/1000 in.

Toe of streambank. That portion of a stream cross section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

Upper bank. That portion of a streambank having an elevation greater than the mean water level of the stream.

Warp of fabric. The direction of the filaments parallel to the long axis of the fabric.

Weatherometer. Device used to expose filter fabric to ultraviolet radiation under specified moisture and temperature conditions. The device is operated in accordance with ASTM E-42-69, "Operating Light and Water Exposure Apparatus (Carbon Arc Type) for Exposure of Non-Metallic Materials." The tensile strength of the filter fabric is then tested in accordance with ASTM D-1682-64, "Tests for Break Load and Elongation of Textile Fabrics."

Woven fabric. Material woven from tape or mono- or multifilament yarn to provide a fairly uniform pattern with distinct and measurable openings.

APPENDIX C: BIBLIOGRAPHY

Advance Construction Specialities Co., Inc. "Sackurity Bags, The Low Cost High Utility Fabric Bag" (not dated), Memphis, Tenn.

__________. "Stop Erosion of Subgrade Material in Water Control Structures, Retain Drainage Designs, Specify Laurel Erosion Control Cloth" (not dated), Memphis, Tenn.

__________. "Typical Designs for Filter Cloth" (not dated), Memphis, Tenn.

Agershou, H. A. 1961 (Feb). "Synthetic Material Filters in Coastal Protection," Journal, Waterways and Harbors Division, American Society of Civil Engineers, Vol 87, No. WW1, pp 111-124.

Aldek, A-S, (Corporation). "Project: Beach Stabilization (Denmark)" (not dated), Odense, Denmark.

__________. "Project: Beach Stabilization (Michigan)" (not dated), Odense, Denmark.

__________. "Project: Breakwater" (not dated), Odense, Denmark.

__________. "Project: Coast Protection" (not dated), Odense, Denmark.

__________. "Project: Dike Construction" (not dated), Odense, Denmark.

__________. "Project: Filter Construction" (not dated), Odense, Denmark.

__________. "Project: Levee Construction" (not dated), Odense, Denmark.

__________. "Project: Weir" (not dated), Odense, Denmark.

Anonymous. 1974 (Mar). "Plastic Cloth Filters Protect Stone Seawalls," Civil Engineering (New York), Vol 44, No. 3, pp 70-71.

__________. 1976 (29 Jan). "Sand-Filled Tubes Cut Cost of Beach Erosion Control," Engineering News-Record, Vol 196, No. 5, p 6.

__________. 1976 (Apr). "Fibre Matting Stabilises Rockfill During Reservoir," Middle East Construction.

__________. 1977 (May). "Assessing Wave Action on Riprap," Water Power and Dam Construction, Vol 29, No. 5, pp 52-53.

__________. 1977 (Dec). "Using Fabrics to the Full," Civil Engineering, (London), Vol 72, No. 12, pp 59-65.

__________. 1978 (Feb). "Fabrics Weave Their Way into Construction," Highway and Heavy Construction, Vol 121, No. 2, pp 27-30.

__________. 1978 (May). "Permeable Membranes," The Consulting Engineer, Vol 42, No. 5, pp 54-59.

__________. 1979 (Feb-Mar). "Geotextile Market at Critical Juncture; A Special GE&C Interview ..." (with Dr. Jean-Pierre Giroud), Geotechnical Engineering and Construction, pp 5-9.

Barrett, R. J. 1966. "Use of Plastic Filters in Coastal Structures," Proceedings, 9th International Conference on Coastal Engineering, Tokyo, pp 1048-1067.

Becker, B. C., and Mills, T. R. 1972 (Aug). "Guidelines for Erosion and Sediment Control Planning and Implementation," Report EPA-R2-72-015, U. S. Environmental Protection Agency, Office of Research and Monitoring, Washington, D. C.; prepared under Project 15030 FM2 by State of Maryland, Department of Water Resources and Hittman Associates, Columbia, Md.

Billet, D. S. 1975 (Nov). "Damming the Dutch Delta," Dupont Magazine (International Ed.), Vol 69, No. 6, pp 2-5.

Bourdillon, M. 1976 (Jun). "Utilisation des Textiles Non-tissés pour le Drainge... (Utilization of Nonwoven Fabrics for Drainage; Application to Fine Soil Embankments in Course of Consolidation)," Report No. 54, Laboratories des Ponts et Chaussées, Paris.

Boyes, R. G. H. 1978 (Dec). "Fabrics," Civil Engineering (London), pp 48-53.

__________. 1979 (Apr). "Fabrics for the Middle East," Civil Engineering (London), pp 41, 43, and 45-46.

Brater, E. F., et al. 1977 (Feb). "The Michigan Demonstration Erosion Control Program in 1976," Michigan Sea Grant Program Technical Report No. 55, University of Michigan, Ann Arbor, Mich.

Burke, P. "Morameal Revetment" (unpublished manuscript), U. S. Army Engineer District, New Orleans, CE, New Orleans, La.

Calhoun, C. C., Jr. 1969 (Oct). "Summary of Information from Questionnaires on Uses of Filter Cloths in the Corps of Engineers," Miscellaneous Paper S-69-46, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

__________. 1970 (Jan). "Interim Report, Investigation of Plastic Filter Cloths," Miscellaneous Paper S-70-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

__________. 1972. "Investigation of Plastic Filter Cloths," M.S. Oklahoma State University, Stillwater Okla.

__________. 1972 (Jun). "Development of Design Criteria and Acceptance Specifications for Plastic Filter Cloths," Technical Report S-72-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Calhoun, C. C., Compton, J. R., and Strohm, W. E. 1971. "Performance of Plastic Filter Cloths as a Replacement for Granular Filter Materials," Highway Research Record, No. 373, pp 74-85.

Carthage Mills, Inc., Erosion Control Division. 1977. "Confused About Which Filter Cloth to Use," Cincinnati, Ohio.

__________. "Eliminate Water-Caused Soil Erosion, Specify; Poly-Filter X, Filter-X, Poly-Filter GB" (not dated), Cincinnati, Ohio.

Carthage Mills, Inc., Erosion Control Division. "Filter Handbook" (not dated), Cincinnati, Ohio.

__________. "Applications of Carthage Mills Woven Plastic Filter Cloths" (various dates), Cincinnati, Ohio.

__________. "Portfolio of Plans and Specifications on Applications of Carthage Mills Filter Fabrics" (various dates), Cincinnati, Ohio.

Cazier, G. 1972 (Jan). "The Use of Bidim Nonwoven Fabric in Public Works," Annales de l'Institut Technique du Batiment et des Travaux Publiques, No. 289, pp 29-41.

Cedergren, H. R. 1976. Seepage, Drainage, and Flow Nets, Wiley, 2d ed., New York.

Celanese Fibers Marketing Co. 1975. "Erosion and Siltation Control with Mirafi 140 Fabric," Report PM-7, Charlotte, N. C.

__________. 1977. "Use of Mirafi 140 Fabric for Embankment and Shoreline Stabilization," Report PM-10, Charlotte, N. C.

__________. 1977. "Use of Mirafi 140 Fabric for Embankment and Shoreline Stabilization," Report PM-12, Charlotte, N. C.

Cooper, R., U. S. Army Engineer District, Savannah, CE, Savannah, Ga., personal communication to E. A. Dardeau, Jr., U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., dated 15 Mar 1978.

Crowe, R. E. 1977 (Jan). "Pensacola Beach Sewage Treatment Plant, Proposal for Shore Protection," Kenross-Naue, Inc., Palm Springs, Fla. (proposal submitted to U. S. Army Engineer District, Mobile, CE, Mobile, Ala.).

__________. 1977 (24 Feb). "Terrafix Interlocking Concrete Block System," Kenross-Naue Canada, Ltd., Rexdale, Ontario, Canada.

Dallaire, G. 1977 (May). "Filter Fabrics Can Cut Costs of River-Bank and Shore-Protection Structures," Civil Engineering (New York), Vol 47, No. 3, pp 74-79.

Dardeau, E. A., Jr. 1978 (29 Mar). "Use of Filter Fabric, by Corps of Engineers (CE) Districts," Memorandum for Record (WESFE), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Delft Hydraulics Laboratory. 1974 (Nov). "Research Conducted into Filter Material-Gobimats," Delft, Netherlands.

__________. 1973. "Gobi-Blocks as Slope Revetments: Stability Under Wave Attack (Extended Summary); Report on Model Investigation," Report M-1184, Delft, Netherlands.

__________. 1973. "Stability of Gobimat and Its Permeability to Sand in Turbulent Flow; Report on Model Investigation," Report R-788, Delft, Netherlands.

DeMent, L. E., Jr. 1976. "Two New Methods of Erosion Protection for Louisiana," U. S. Army Engineer District, New Orleans, CE, New Orleans, La.; prepared for presentation at the 15th International Coastal Engineering Conference, Honolulu, Hawaii.

Dunham, J. W., and Barrett, R. J. 1974 (Feb). "Woven Plastic Cloth Filters for Stone Seawalls," Journal, Waterways, Harbors, and Coastal Engineering Division, American Society of Civil Engineers, Vol 100, No. WW1, pp 13-22.

DuPont Company, Explosives Products Division. 1977 (Sep). "How to Solve Soil Erosion and Siltation Problems with Typar," Wilmington, Del.

Fairley, J. G., et al. 1970 (Jun). "Use of Plastic Filter Cloth in Revetment Construction," Potamology Investigations Report 21-4, U. S. Army Engineer District, Memphis, CE, Memphis, Tenn.

Franco, J. J. 1965 (Dec). "Effects of River Stages on Bank Stabilization; Analysis of Field Data," Potamology Investigations Report 20-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Garrett, L. S., and Butler, D. W. 1977 (14 May). "Engineering and Design, Use of Plastic Filter Cloths in Subdrainage Systems," Engineering Technical Letter 1110-3-261, Headquarters, Department of the Army, Office of the Chief of Engineers, Washington, D. C.

Edward E. Gillen Co. "New Longard Tubing Saves Beach Properties" (not dated), Milwaukee, Wis.

Giroud, J.-P. 1977. "Geotextiles (Les Geotextiles)," Le Moniteur, pp 61-67; translated from the French by the Ralph McElroy Co., Custom Division, Austin, Tex.

Giroud, J.-P., Girouc, J. P., and Bally, F. 1977 (Aug). "Behavior of a Nonwoven Fabric in an Earth Dam," University of Grenoble, Grenoble, France; translated from the French by the Ralph McElroy Co., Custom Division, Austin, Tex.

Haliburton, T. A., Anglin, C. C., and Lawmaster, J. D. 1978 (May). "Selection of Geotechnical Fabrics for Embankment Reinforcement," U. S. Army Engineer District, Mobile, CE, Mobile, Ala.; prepared by Oklahoma State University, Department of Civil Engineering, Stillwater, Okla., under Contract DACW 01-78-C-0055.

Hallmark, C. G. U. S. Army Engineer District, St. Paul, CE, personal communication to E. A. Dardeau, Jr., U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., dated 23 Mar 1978.

Headquarters, Department of the Army, Office of the Chief of Engineers. 1969. "Report of the Chief of Engineers to the Secretary of the Army on a Study of Streambank Erosion in the United States," Washington, D. C.; prepared for the U. S. House of Representatives Committee on Public Works.

__________. 1977 (Nov). "Civil Works Construction Guide Specification, Plastic Filter Fabric," CW-02215 (Superseding Oct 1975 specification), Washington, D. C.

Healy, K. A. and Long, R. P. 1974 (Apr). "Prefabricated Fin Underdrain Promises Faster Soil Drainage," Civil Engineering (New York), Vol 44, No. 4, pp 50-53.

Highfill, R. E., and Kimberlin, L. W. 1977. "Current Soil Erosion and Sediment Control Technology for Rural and Urban Lands," Proceedings, National Symposium on Soil Erosion and Sedimentation by Water, American Society of Agricultural Engineers, Chicago, Ill., pp 14-22.

Hoare, D. J. 1978 (Jul). "Permeable Synthetic Fabric Membranes 1, Their Use in the Strengthening of Soils," Ground Engineering, Vol 11, No. 5, pp 33-37.

_________. 1978 (Nov). "Permeable Synthetic Fabric Membranes 2, Factors Affecting Their Choice and Control in Geotechnics," Ground Engineering, Vol 11, No. 8, pp 25-31.

Hoogendoorn, A. D., and Ognik, H. J. M. 1975. "Investigation of the Hydraulic Characteristics of Synthetic Filters," Polytechnic Magazine (Dutch), Vol 30, No. 15, pp 477-484, and No. 16, pp 515-522.

Hoogendoorn, J. 1977 (Apr). "A Case History on the Large Scale Application of Woven Synthetic Filter Fabrics on the Banks of the River Yssel," Proceedings, Internation Conference on the Use of Fabrics in Geotechnics, Association Amicale des Ingenieurs, Anciens Elèves de l'E.N.P.C., Paris, pp 243-247.

Hunt, I. A., Jr. 1959 (Sep). "Design of Seawalls and Breakwaters," Proceedings, American Society of Civil Engineers, Vol 85, No. WW3, pp 123-152.

Hurst, C. K., and Brebner, A. 1969. "Paper, Shore Erosion and Protection, St. Lawrence River, Canada," Inland Navigation (Section 1); Principles Governing the Design and Construction of Economic Revetments for Protecting the Banks of Rivers, and Canals for Ocean- and Inland-Navigation (Subject 6), XXIInd International Navigation Congress, PIANC, Paris.

ICI Fibres. 1974 (Apr). "Land Reclamation," Yorkshire, England.

_________. 1974 (Apr). "River Bank Protection with Revetments (Dytap Random Masonary Faced Interlocking Concrete Blocks)," Yorkshire, England.

_________. 1974 (Apr). "River Bank Protection with Revetments (Reno. Mattress)," Yorkshire, England.

_________. 1974 (Sep). "Hunterston Iron Ore/Coal Terminal, 'Terrami' Used as Part of Specified Design," Case Study Report C12/1, North Yorkshire, England.

_________. 1976 (Feb). "River Bank Protection with Revetments (Stone Revetments)," North Yorkshire, England.

_________. 1976 (Jun). "Coastal Protection," Yorkshire, England.

Ingles, O. G. 1977 (Apr). "The Permeability of Geotechnical Fabrics, Its Reduction, and Modification to Suit Particular Uses," Proceedings, International Conference on the Use of Fabrics in Geotechnics, Association Amicale des Ingenieurs, Anciens Elèves de l'E.N.P.C., Paris, 323-327.

Kenross-Naue, Inc. "If Erosion Control Is Your Responsibility, Terrafix Can Be Your Answer" (not dated), Palm Springs, Fla.

Keown, M. P., and Dardeau, E. A., Jr. 1979 (Jun). "Section 32 Program; Field Inspection of Morameal Revetment on the Red River," Inspection Report 7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Keown, M. P., et al. 1977 (May). "Literature Survey and Preliminary Evaluation of Streambank Protection Methods," Technical Report H-77-9, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Kerwin, J. L. 1974 (21 Apr). "State Hunts Cheap Way to Save Receding Shores," The Detroit Sunday News, Detroit, Mich.

Klassen, E. W. 1976 (Apr). "Synthetic Fabrics in Civil and Hydraulic Engineering," Engineering Digest, Vol 22, No. 4; Reprinted by Staff Industries, Inc., Detroit, Mich., as Information Service Bulletin No. 093077.

Koerner, R. M., and Welsh, J. P. 1979 (Dec). Construction and Geotechnical Engineering Using Synthetic Fabrics, Wiley, N. Y.

Lavagnino, S. 1974 (May). "Gabions Guard River Banks Against 50,000-cfs Flow," Civil Engineering (New York), Vol 44, No. 5, pp 88-89.

Lewis, M. 1977 (Nov; appended Jan 1978). "Bibliography on Construction Fabrics" (Draft), Oregon State University, Department of Civil Engineering, Corvallis, Oreg.

Lipscomb, E. B., and Otto, W. C. Paper, Inland Navigation (Section 1), New Materials and Methods for Protecting the Banks and Bottoms of Canals, Rivers, and Ports and Their Costs and Relative Advantages (Subject 4), XXIst International Navigation Congress, PIANC, Stockholm, 1965, pp 133-150.

List, H. J. 1973. "Investigations of Synthetic Filters Applied in Hydraulic Structures Under the Influence of Non-Stationary Flow," Mitt. Bl. Bundesanst., No. 35, pp 123-147.

__________. 1977 (Apr). "Woven and Nonwoven Fabric Filters in Waterway Engineering, Test and Dimensioning," Proceedings, International Conference on the Use of Fabrics in Geotechnics, Association Amicale des Ingenieurs, Anciens Elèves de l'E.N.P.C., Paris, pp 339-344.

Littlejohn, B. J. 1977 (Aug). "Use of Plastic Filter Cloth in Revetment Construction, Follow-up Study," Potamology Investigations Report 21-5, U. S. Army Engineer District, Memphis, CE, Memphis, Tenn.

Maccaferri Gabions, Inc. 1971. "Maccaferri Gabions," Flushing, N. Y.

Marks, B. D. 1975. "The Behavior of Aggregate and Fabric Filters in Subdrainage Applications," University of Tennessee, Knoxville, Tenn.

McGuffey, V. C. 1978 (May). "Filter Fabrics for Highway Construction," Highway Focus, Vol 10, No. 2, pp 1-21.

McKeand, E. 1978 (Oct). "Textile Reinforcements - Characteristics

Properties and Their Measurements," Ground Engineering, Vol 11, No. 7, pp 13-16 and p 22.

Meyer, H. 1972. "The Construction of Permeable, Protective Embankment Surfaces Underwater in Shipping Canals During Use," Zeitschrift fur Binnen Schiffart und Wasserstraben, Vol 4, pp 137-142.

__________. 1974 (21 Oct). "Statement to Ministry of Natural Resources," Chatham, Ontario, Canada.

Miller, S. D. 1977 (Apr). "Filter Fabrics, State of the Art Paper," Vicksburg, Miss.; prepared for Course No. CE 8913, Earth and Rock Fill Dams, Mississippi State University, Vicksburg Graduate Center, Vicksburg, Miss.

__________. 1978 (Feb). "Bank Distress of Low Water Weirs on Big Creek, Louisiana," Miscellaneous Paper S-78-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

__________. "Filter Fabric Work at WES" (unpublished and undated manuscript), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Monroe, J. E. 1977 (18 Mar). "Inspection of Mid Lake Culverts," Memo for Record (LMMED-F), U. S. Army Engineer District, Memphis, CE, Memphis, Tenn.

Monroe, J. E., Skinner, J. E., and Turner, T. B. 1977 (19 Oct). "Investigation of Reported Slides and Erosion at W. G. Hustable Pumping Plant," Memo for Record (LMMED-F), U. S. Army Engineer District, Memphis, CE, Memphis, Tenn.

Monsanto Textiles Co. "Bidim Engineering Fabric for Soil Stabilization and Drainage," St. Louis, Mo.

Naue-Fosertechnik. 1974. "Shore Protection on Lake Erie, Canada," Terrafix Information 2'74, Espelkamp-Fiestel, West Germany.

__________. "Terrafix, Terra Dran" (not dated), Espelkamp-Fiestel, West Germany.

Nicolon B-V (Corporation). "Adaptation of Oude Maas River Profile at the Spijkenisse Bridge" (not dated), Enschede, Netherlands.

__________. "List of References of Important Marine Works and Road Constructions for Which Nicolon Synthetic Fiberfabrics and/or Constructions Were Used" (not dated), Enschede, Netherlands.

__________. "Nicolon Buideldoek, Pocket Fabric" (not dated), Enschede, Netherlands.

__________. "Portfolio of Translated Case Histories" (various dates), Enschede, Netherlands.

__________. "Specify Nicolon Filter Fabrics for Hydraulic Engineering, Road Construction, Erosion Control, Drainage, and Other Uses" (not dated), Baton Rouge, La.

__________. "Stabilenka" (not dated), Enschede, Netherlands.

Normann, J. M. 1975 (Oct). "Design of Stable Channels with Flexible Linings," Hydraulic Engineering Circular No. 15, U. S. Department of Transportation, Federal Highway Administration, Washington, D. C.

Ogink, H. J. M. "Investigations on the Hydraulic Characteristics of Synthetic Fabrics," Publication No. 146, Delft Hydraulic Laboratory, Delft, Netherlands.

Patrick, D. A. 1974. "Filter Design Criteria and Their Application," Ph.D. Dissertation, Oklahoma State University, Stillwater, Okla.

Rosen, W. J., and Marks, B. D. 1975. "Investigation of Filtration Characteristics of a Nonwoven Fabric Filter," Transportation Research Record, No. 532, pp 87-92.

Savage, R. P. 1958 (May). "Wave Run-up on Roughened and Permeable Slopes," Proceedings, American Society of Civil Engineers, Vol 84, No. WW3, Paper 1640, pp 1640-1 - 1640-38.

__________. 1959. "Laboratory Data on Wave Run-up on Roughened and Permeable Slopes," Technical Memorandum 109, U. S. Army Corps of Engineers, Beach Erosion Board, Fort Belvoir, Va.

Saville, T., Jr. 1956. "Wave Run-up on Shore Structures," Proceedings, American Society of Civil Engineers, Vol 82, No. WW2, Paper 925, pp 925-1 - 925-14.

Schuster, D. E. 1978 (10 Jul). U. S. Army Engineer District, Kansas City, CE, Kansas City, Mo., personal communication to E. A. Dardeau, Jr., U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Seemel, R. N. 1976 (Mar). "Plastic Filter Fabrics Challenging the Conventional Granular Filter," Civil Engineering (New York), pp 57-59; reprinted by Staff Industries, Inc., Detroit, Mich., as Information Service Bulletin No. 080676.

Snaphaan, B. 1978 (23 Aug). Nicolon B-V technische-en industriele weefsels, Enschede, Netherlands, personal communication to Dr. J. R. Rogers, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Snip, J. G. 1962. "Man-Made Fibres in Dyke Building," Proceedings, Second World Congress of Man-Made Fibres, London.

Snyder, G. 1977 (27 Aug). "$11.6 Million Saginaw Bay Project Nears Halfway Point," Michigan Contractor and Builder.

Soil Testing Services, Inc. 1967 (5 Jul). "Poly-Filter X," Northbrook, Ill.

__________. 1967 (13 Jul). "Filter-X," Northbrook, Ill.

Staff Industries, Inc. "Staff Permealiner Erosion Control Material for Subsurface Draining, Road and Soil Stabilization," Detroit, Mich.

Steward, J. E. 1975 (13-15 Aug). "Use of Woven Plastic Filter Cloth as a Replacement for Graded Rock Filters," Proceedings, Twenty-Sixth Annual Highway Geology Symposium, Coeur D'Alene, Idaho, pp 101-114.

Steward, J. E., Williamson, R., and Mohney, J. 1977 (Jun). "Guidelines for Use of Fabrics in Construction and Maintenance of Low Volume Roads," U. S. Department of Agriculture, Forest Service, Portland, Oreg.; reprinted 1978 by U. S. Department of Transportation, Federal Highway Administration, Office of Research and Development as Report No. FHWA-TS-78-205.

Stoller, F. L. 1978 (13 Apr). Phillips Fibers Co., Greenvile, S. C., personal communication to M. P. Keown, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Tan, H. H. 1978 (31 Mar). E. I. DuPont de Nemours and Co., Wilmington, Del., personal communication to M. P. Keown, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Terra Aqua Conservation. 1976. "Bekaert Gabions," Reno, Nev.

U. S. Army Engineer District, New Orleans, CE. 1977 (4 Feb). "Advance Copy, Civil Works Construction Guide Specification for Plastic Filter Fabric," Disposition Form from Chief, Hydraulics and Hydrology Branch, to Chief, Foundations and Materials Branch, New Orleans, La.

_________. 1977 (16 Feb, 18 Feb). "Review of Plans and Specifications for Maria Realinement," Disposition Forms from Chief, Design Branch, to Chief, Foundations and Materials Branch, and from Chief, Foundations and Materials Branch, to Chief, Design Branch, New Orleans, La.

_________. 1977 (28 Jan, 3 Mar, and 9 Mar). "Review of Plans and Specifications for Maria Realinement, Mile 101.3 to 102.4, Rapides Parish, La.," Disposition Forms from Chief, Hydraulics and Hydrology Branch, to Chief, Design Branch, and from Chief, Design Branch, to Chief, Hydraulics and Hydrology Branch, New Orleans, La.

_________. 1977 (21 Jul). "Review of Plans and Specification for Whittington Revetment, Mile 89.8R, Rapides Parish, La.," Disposition Form from Chief, Hydraulics and Hydrology Branch, New Orleans, La.

U. S. Army Engineer District, Norfolk, CE. 1972 (Oct). "Shoreline Erosion Study for Anderson Park, Newport News, Virginia," Final Expanded Reconnaissance Report, Norfolk, Va.

U. S. Army Engineer District, San Francisco, CE. 1978 (May). "Shoreline Erosion Control Demonstration Program, Alameda, California," Draft, Preconstruction Report, San Francisco, Calif.

U. S. Army Foreign Science and Technology Center. 1972. "For the First Time Terrafix Makes Possible and Effective Underwater Filter," Translation No. 23-869-72, Charlottesville, Va.

U. S. Department of Transportation, Federal Highway Administration. 1977 (May). Highway Focus, Vol 9, No. 1; entire publication devoted to filter fabrics.

_________, Office of Research and Development. 1978. "Sample Specifications for Engineering Fabrics," FHWA-TS-78-211, Washington, D. C.

United States Filter Corp. Menardi Southern Division. "Protect Supporting Soils, Specify Monofilter" (not dated), Houston, Tex.

United States Textures Soils Corp. (now Nicolon Corp.). "Nicolon Filter Cloths for Hydraulic Engineering System, Marine Use, Highway Construction Erosion Control" (not dated), Baton Rouge, La.

__________. "Specify Nicolon Filter Fabric for Hydraulic Engineering, Road Construction, Erosion Control, Drainage and Other Uses," Baton Rouge, La.

Van Lookeren Campagne, J. P. A. 1963 (Jan). "Use of Nylon in Hydraulic Engineering," Civil Engineering (New York), Vol 33, No. 1, pp 31-33.

Vollor, T. W. 1978 (Dec). "True Load-Deformation Relationships for Coated and Uncoated Fabrics," Miscellaneous Paper S-78-17, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Working Party on Synthetic Materials in Earthworks and Civil Engineering Hydraulics of the German Society for Soil Mechanics and Foundation Engineering. 1975. "Recommendations for the Use of Synthetic Materials in Earthworks and Civil Engineering Hydraulics," Boutechnik, Vol 52, No. 12, pp 397-402.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Keown, Malcolm Price
  Utilization of filter fabric for streambank protection applications / by Malcolm P. Keown, Elba A. Dardeau, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.
  48, [70] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-80-12)
  Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Work Unit 3, Authorized by Section 32, Water Resources Development Act, 1974.
  Includes bibliographies.

1. Bank protection. 2. Filter fabrics. 3. Stream erosion. I. Dardeau, Elba A., joint author. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-80-12.
TA7.W34 no.HL-80-12